LABORATORY CONSTRUCTION AND EQUIPMENT

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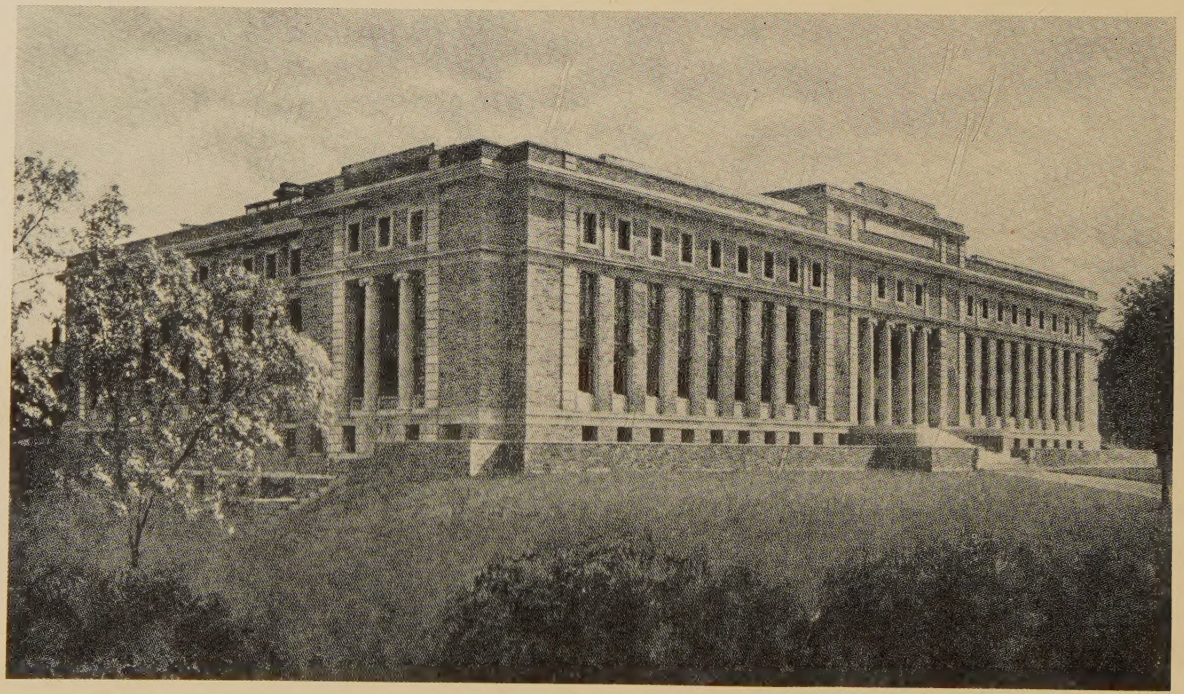
The Construction and Equipment of Chemical Laboratories



Baker Laboratory, Cornell University.

A Report

OF THE

National Research Council. Committee

ON

The Construction and Equipment of Chemical Laboratories

THE CHEMICAL FOUNDATION, INCORPORATED
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FOREWORD

When in November, 1924, the National Research Council Committee on the Construction and Equipment of Chemical Laboratories was first formed, it was not realized how wide was the field of its usefulness, nor how important a part it could play in furthering the cause of Chemistry. But from its beginning, appeals for help in the planning and construction of laboratories came to the Committee in such numbers as to show the lack of sources of definite information to meet the needs of planners and builders of new laboratories. To obtain the necessary data, requests for floor plans and specifications were sent to the directors of recently constructed laboratories, and a questionnaire, to which the response was cordial, was sent to the heads of departments of Chemistry in over a hundred colleges and universities to obtain definite answers to leading questions as to the requisites for a practical laboratory building. The results of this questionnaire were correlated and are embodied in the text of the various chapters along with the personal experience of the members of the Committee, all of whom have planned and built chemical laboratories within the last ten years, and are acquainted with modern practice in laboratory construction.

The aim of the work is to aid chemists in preparing preliminary plans for new laboratories or the improvement of those already built, to furnish architects and engineers with dependable information of the special needs of chemical laboratories, and to discuss critically the various materials available for their construction and equipment; in a word, to supply the data of general interest regarding the present status of chemical laboratory construction and equipment. The guiding thought throughout has been simplicity of arrangement with a maximum of service.

Necessarily, only general rules or suggestions can be put forward by the Committee as the planning of every laboratory constitutes a problem which must be solved locally in each case since

such variables as curriculum, educational policy, the number of students, present or prospective, in the various courses of study, and the available appropriation all occur. While college and university laboratories form the burden of the text, an effort has been made to include special types of laboratory and their general equipment. The particular *apparatus* for special courses, varying with the nature of the course, the text-book followed, or the personal views of professors, is amply provided for in apparatus catalogues and need not be set down here. In the description of the requirements for the varying types of laboratories, written by different collaborators, there may occur, at times, repetition of details given in other chapters, but it has been deemed better to leave them in their context rather than to break the continuity by cross-references to the special chapter dealing with that topic.

Well aware that there are widely divergent views on laboratory planning, due to varied experience and the personal equation of planners, as well as to local needs, and inasmuch as the planning of chemical laboratories usually is placed in the hands of a chemist and an architect who have not had previous experience in this field, the Committee has endeavored to give of its best and the suggestions in this book have been brought together in the hope that they may prove helpful to those who have been burdened with the complicated and perplexing task of planning chemical laboratories.

The Committee wishes to record here its sincere thanks to Mr. Francis P. Garvan, President of The Chemical Foundation, whose generosity provided the needed funds for collecting the data and preparing the material for printing, as well as for defraying the expense of publication, thus enabling it to offer the book to laboratory-planners at a nominal price. It wishes also to acknowledge its indebtedness to Dr. James F. Norris, former Chairman of the Division of Chemistry and Chemical Technology of the National Research Council, through whose initiative our Committee was created and appointed. Its gratitude is expressed to those who contributed chapters on special types of laboratories and whose authorship is there acknowledged, as well as to Dr. Maurice Holland, of the Engineering Foundation, Dr. C. J. West, of the National Research Council, Dr. Robert S. Williams, of the Massachusetts Institute of Technology, and especially to Dr. J. H. Mathews, a former member of this Committee, for valuable advice and assistance. Its

thanks are also due to the directors of chemical laboratories who kindly furnished cuts, photographs, or floor plans of their buildings, and to the laboratory equipment firms who allowed the use of their catalogues, and, in some cases, have supplied special information and illustrations, and particularly to Mr. A. C. Monahan, of the Kewaunee Manufacturing Co., Mr. Paul H. Johnson, of E. H. Sheldon Co., and Mr. W. E. Atkins, of the Alberene Stone Co.

The work of revision and criticism of individual chapters has been shared in part by members of the Committee, but has fallen most heavily on Professor Dennis and the Chairman. As far as it is possible to place the responsibility for the major portion of the material, it has been done at the head of each chapter, though at times in the interest of unity, the Chairman has assumed the responsibility of modifying the original manuscripts. The Committee will welcome suggestions and constructive criticism concerning any of the topics mentioned in this report. It also expresses the hope that the value of its publication may be in some part commensurate with the time and labor spent on its production.

L. M. Dennis, Cornell University,
C. R. Hoover, Wesleyan University,
L. W. Mattern, McKinley High School,
J. N. Swan, University of Mississippi,
G. L. Coyle, S. J., Georgetown University,
Chairman.

CHAPTER I

THE PLANNING OF A CHEMICAL LABORATORY

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Director, Department of Chemistry, University of Mississippi,
and
G. L. Coyle
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The planning of a Chemical Laboratory is an intricate task both for an architect and a chemist. For the architect, because it involves questions concerning materials, floor plans, plumbing, ventilation, and administration of the completed structure which are quite outside of his usual practice, and with which only a few architects possess more than casual and vague acquaintance. For this reason success in the planning of a laboratory of Chemistry can be achieved only through intimate and sympathetic cooperation between the architect and the chemists who are later to use the building. The chemist, before beginning the preparation of plans, should know, partly from his own experience, but still more from inspection of other laboratories or the study of their printed descriptions, just what features of plan and equipment should be embodied by the architect in his design. The architect, on the other hand, should inform himself as fully as possible as to the manner in which the problems with which he will have to deal have been solved in other laboratories.

Preliminary Steps in Planning. As the unit of a laboratory is a working table of a certain width, an aisle, another table, etc., to which the windows should conform, and as the number of tables as well as the seating capacity of lecture and recitation rooms will depend on the student attendance, and the number of private laboratories and offices of professors will vary with the

student body, before beginning to plan a laboratory that will be adequate for present and future use, it will be necessary to determine the number of students and faculty it is to accommodate, the different courses to be given, the probable number of students in each course, and the changes anticipated for a definite period of time. This will require a knowledge of the average number of students who have taken the various courses, say within the last ten years, and a calculation based on these factors to determine the probable rate of increase in attendance for the fixed period. This will give a fairly definite idea of the space required.

Educational Policy. In coming to this decision many other factors will have a decided effect on the planning. There is the policy of the institution as to indefinite expansion or for restriction to a definite limit of attendance,—a maximum beyond which its student body will not be permitted to grow. The limitation of numbers lessens the difficulty very largely, but where provision must be made for future increase during a definite period, the location and the shape of the building must be such that additional units may be added without causing inconvenience or destroying the relationship of rooms to the general plan.

Curriculum. The curriculum is another important element in the planning, as the courses to be given, or introduced later, according to local needs or the changing character of science or science teaching, and the distribution of the students in the varied courses, all affect the number and sizes of rooms and the disposal of these rooms in regard to convenience in use and relation to lecture and service rooms and to piping systems. One must consider and decide whether the probable addition of new courses will have taken place before the building will have reached the limit of its capacity.

Floor Plans. When these variable factors have been determined at least in a general way, the next step will be the designing of floor plans. These are not merely a matter of the number and sizes of rooms, and their relative location to each other for convenience and service, but also have reference to the position of electrical conduits, piping, heating, and ventilating systems, as well as lighting. To these may be added the consideration of the correlation of chemical units with architectural units, such as location of piping, vents, windows, radiators, etc., in respect to the design of the building. Professional architects

are hardly qualified to design a laboratory without the close cooperation of the chemist in charge.

Financial Restrictions. Another disturbing element in planning is the amount of money available for the erection of a laboratory. When the chemist has settled definitely the plans of a desirable, practical laboratory building, the question of cost at once arises. Where no restriction is placed on the cost of building and equipment, which is rare indeed, this factor of the problem is minimized or eliminated. But where the appropriation is limited to a definite sum, and a budget is enforced, the planner is restricted both as to the type and size of building, and as to its future maintenance cost. If the builder must make the exterior conform to styles or types of building already existing on the campus, there is an added difficulty, and the cost, which varies from 40-90 cents per cubic foot, according to the type of building, may restrict the desirable size of the building or its necessary equipment, and the ideal plans of the chemist degenerate into a makeshift.

It would be helpful at this point if the architect would furnish the data for a discussion of the cost per square foot or cubic foot of already completed laboratory buildings, such memoranda being offered as suggestions from which the chemist might find it possible to work out something definite as to type and size of building within his means. One of the greatest sources of delay in getting a building program started, and incidentally, one which involves extra expense to the architect as well as to the builder, is the including of many visionary ideas in a building or plans, all of which must be revised downward or entirely out, before building can proceed. The following data are derived from recently constructed chemical laboratories of different sizes and furnish percentage costs of various items of building:

	A	B	C
Cubic Footage	370,000	1,400,000	2,000,000
General Construction	60.7%	67.2	57.4
Plumbing, Heating, Ventilation	23	16	16
Electrical Installation	4	2.4	6.8
Equipment	12.4	14	19.8
Cost per cu. ft.	$ .35	$ .27	$ .80

Less detailed data as to the cost of the various elements of laboratory construction, giving, however, approximate sizes and costs of recent buildings, are contained in the subjoined table:

Floor Area (Sq. Ft.)	*Approximate Dimensions Over All (Feet)*	*Capacity Cu. Ft.*	*Total Cost*	*Cu. Ft. Cost*
36,000	154 x 73 x 55	523,300	$ 475,000	$ .90*
221,169	268 x 192 x 70	2,431,506	1,500,000	.62
120,000	200 x 150 x 60	2,000,000	430,000	.215
150,000	335 x 260 x 30	2,800,000	1,875,000	.68
32,000	200 x 52 x 60	650,000	340,000	.52
56,160	195 x 82 x 50	630,000	300,000	.48
85,000	79 x 305 x 60	1,450,000	500,000	.34
32,623	122 x 76 x 47	435,000	380,000	.87*

*Completely equipped.

The financial administration of educational and industrial institutions must not be surprised if chemical laboratory construction, owing to the costly nature of plumbing and extra ventilation (about 25% of the total cost), is more expensive per student or worker than any other type of building. Industries throughout the country have made a greater outlay for chemical buildings than for biological or physical testing laboratories.

Various Solutions of the Money Problem. To meet this prevailing lack of funds, planners have resorted to various devices, none of which is entirely satisfactory. Some have used the flexible unit-plan of building, with fewer units and decreased space, but with each unit complete, to which, later on, additions may be made without disrupting the original plan; others have erected the building as planned, but have left the rooms only partially equipped, to be completed when funds allow; while still others have made complete plans, but constructed, at first, only a part of the building, leaving the rest to be built when the money is available. This, however, does not seem to meet more than temporary needs. It is generally agreed that it is a waste of money to put in poor materials or to cheapen construction to meet the reduced appropriation, or even to erect temporary buildings, as the expense of plumbing and ventilation and the labor cost of installation, are relatively high as compared to the total cost of building. It is almost impossible later on to salvage chemical equipment installed in an old or temporary building. The cost of dismantling this building for which the plumbing

and electrical work, fixtures, etc., were designed, and recutting and refitting these for another building, raises the question whether it would not be cheaper to use entirely new material and sell the old for its junk value.

Architect and Chemist. Further difficulty arises from the clashes of opinion between the architect and the chemist, owing to the fact that each lacks clear understanding of the fundamental demands of the other, which leads to a wrong relation between them. A great deal of difficulty has been experienced with architects on the interior planning of the equipment. Architects' experience is usually very good for exteriors; they can design an artistic building, they can design and estimate all the engineering phases of a building, but when it comes to the laying out of the rooms for chemistry in the best proportions and according to the best plan, and the engineering involved in the equipment with its plumbing, electrical, and other phases, the architect is notoriously weak, entirely for the reason that he is so busy on his exteriors that he is unable to keep abreast of the times on equipment, with its accessory requirements. Some years ago it was a common practice for the architect to sit in with the heads of the departments, and let each individual chemist try to describe what he wanted in his laboratory; then the architect would go out and have his draftsman follow this detail as carefully as he could. The result was largely an experiment, because the architectural designer and draftsman had no idea of the requirements of laboratory furniture, or the services incident to it. The chemist knows what he wants, but there are so many details to be thought of in connection with a unit of this type, that the chemist rarely has them all in mind, with the result that the plan and the specifications often are very faulty and incomplete. But, if the special equipment is handled by experienced contractors, they are in a position to advise as to the items required to produce a satisfactory equipment. Many architects write specifications which over-emphasize exteriors and do not leave sufficient funds for satisfactory interior installations and equipment.

A chemical building, in order to be utilized to the best advantage, should be built around the equipment. Preliminary floor plans should be made, all equipment should be detailed carefully in the floor plans, and they should be set, reset, and further con-

sidered; the average chemist is prone to overlook the vertical elevation of equipment. For this reason, typical elevations should be made up and scanned by a competent laboratory engineer. Adequate aisle spaces should be provided; also adequate door openings to permit the bringing in of bulky equipment.

A typical equipment layout should be made of each room, or of each floor to show its correlation with others. The scale of these plans should be not less than ¼ in. and preferably ½ in. per foot. Then a committee should be appointed to carefully consider the matter of coordination between equipment and building. On this committee there should be the interested members of the Department of Chemistry, a representative from the architectural organization, and a representative from the engineering organization. A separate corps of engineers usually is desirable on a laboratory building. This should be an engineering organization which has had previous experience in developing laboratory equipment. Where the architect handles the entire engineering, the best results are not always obtained, because the architectural organization is usually more concerned with the outside architecture than with the engineering of the laboratory equipment. Where all these matters are worked out in common, previous to the beginning of the building, complete details can be secured of all phases. The committee, as previously indicated, can act as coordinators, all contracts for the fixed equipment should be let preferably at one time, as well as the mechanical, plumbing, electrical, ventilation, sheet metal, and other items. Cooperation between architect and chemist is vitally important. Each should be willing to sacrifice a desirable non-essential for a fundamental in the other's domain. It has been said that "an architect who really meets the problem of designing a chemical laboratory is one who will put a building around the chemist's plan."

The chemist-planner will find in the chapters that follow detailed suggestions, which taken in conjunction with the experience derived from visits to fairly recent laboratories and conferences with their directors and members of the faculty (the stock room manager and janitor can also give helpful hints), and a study of their methods of solving similar problems will enable him to plan and erect a practical, well-equipped chemical laboratory—"a consummation to be devoutly wished."

General Arrangement of Laboratory

Nature of Laboratory. The notion sometimes prevails that a laboratory is a laboratory and that all laboratories are alike. All laboratories are not alike, nor should they be. Even chemical laboratory rooms should differ from each other in different parts of the same building. A chemical laboratory is neither a shop, in the ordinary sense of that word, nor is it "an ornate monument" as some one has put it. It is a working place, but a refined working place,—a shop comparable to those where delicate operations are carried out. It must be clean, it must be conveniently arranged, it must be complete, it must have good materials in its construction and in its equipment, it must be fitted for the purpose for which it is to be used.

Housing Several Sciences Together. A chemical laboratory will naturally be quite different from an engineering or a physical laboratory. For this reason it is not desirable to build a single building to house a number of scientific subjects. However, this is at times necessary in the smaller colleges. The question then arises as to the best arrangement for such a building. Two general methods suggest themselves at once,—to give a floor to each subject, or to divide the building perpendicularly. It is very important to consider the factors entering into this problem. Of all the sciences, chemistry should be the last to be housed with another science. The major reason for this is the fact that chemical workers handle so many substances which give off corroding or irritating fumes. Although the best systems of ventilation may be used, it still remains true that the chemical laboratory will contain fumes. It is possible to carefully isolate a room so that the fumes do not get into it, and this is done with balance rooms, distilling rooms, and others in a chemical laboratory. If another science which uses easily corroded instruments is to be located adjacent to chemical laboratories, great care must be exercised that these laboratories be protected from the chemical fumes. If these laboratories are on the same floor with the chemical laboratories it is evident that there must be complete partitions between the two sciences with a doorway in the corridor and this door should usually be kept closed.

Chemical Laboratory Location. If all the laboratories for one subject are placed on a separate floor that arrangement must be made which will best protect them from these fumes. In

general, it is best to put chemistry on the upper floor if the plan of putting a science on a single floor is followed, as the tendency of many chemical fumes is upwards rather than downwards. It is true that some fumes are heavy and have a tendency to fall, but on the whole, the more corrosive fumes, such as hydrochloric acid, have a tendency to rise under the conditions in which they are given off. The currents of air in ventilation are usually upward and therefore have a part in carrying these fumes upward rather than downward, and if the out-take of the ventilator is located on the lower part of the wall, it will care for any heavy gases that may be liberated.

Perpendicular Divisions of Building. If the perpendicular method of division is used, the chemical laboratories must of necessity be on the same floor with laboratories of other subjects. This is not as satisfactory a method as the floor method. The fume problem is a serious objection to this method of arranging the sciences. Another objection to the perpendicular plan is that it involves much more stair climbing. It is always necessary for those working in a given science to have access to the various rooms used for the subject. Particularly are the teachers called upon to pass from one room to another. If the perpendicular method is used they must do much stair climbing. Again, a chemical laboratory which shares a building with other sciences can usually provide only a single stock room. This perpendicular arrangement will require much climbing of stairs on the part of students to get materials from the stock room. Another objection to this arrangement is the question of getting apparatus and supplies to the various floors. If separate elevators are used for each subject it increases the expense, while a single elevator will do for all if the floor method of separation is used. Another objection to the perpendicular plan is that there must either be additional stairways or else the corridors will be too open between the different subjects. If four sciences are to be accommodated in the same building, then there would be four stairways which would add to the expense and require considerable space.

One favorable aspect of the perpendicular method is the matter of plumbing. Some sciences do not need elaborate plumbing, but chemistry does. If the chemical laboratories are placed one above the other the arrangement of the plumbing is much

simplified. On the other hand, every science must have some plumbing and needs to have most of the risers that are used in a smaller chemical laboratory. Another fact in favor of the perpendicular arrangement is that a chemical laboratory should have storage space in the basement or ground floor to give a cool place in warm weather. Of course, the floor method can be used and some basement rooms given over to chemistry for this purpose although the chemical laboratories may be on another floor. On the whole, it is better to use a single floor for a given science rather than make a perpendicular division of the building. This conclusion is reached from consideration of the experience of those who have used the two plans. If it is possible, it is far better to have a separate building for chemistry alone. Other sciences like biology, physics, geology, etc., can be housed together better than can chemistry with any other science.

A chemical laboratory is somewhat unique among laboratories. The arrangement of parts in the building differs from other laboratories. The experiments are peculiar in that the composition of materials is continually being changed and new products formed. Many of these substances that are used, as well as the products that are formed, are corrosive materials and a number are very active gases. In addition, many students are working at the same time with these corrosive materials which are present in large quantities. This calls for peculiar ventilation for the protection of the apparatus and equipment. In a chemical laboratory the working units must be as many as the student workers and even more, hence, large rooms are called for with many work tables with individual working spaces. Moreover, these tables must be supplied with water and gas and in many laboratories with steam, hot water, air pressure, suction and other general utilities which are to be used by the individual workers. Much apparatus is handled and many pieces must be supplied and located ready for use. The experiments vary widely in their character, some requiring only simple appliances, and others requiring the greatest exactness with most delicate instruments which must be handled with extreme care. All this calls for elaborate plumbing and ventilating systems which must be correlated so as to get the best results and secure uniform working conditions. This is much more of a problem here than in other laboratories. These plumbing and ventilating systems

must be so arranged that they are accessible in case of trouble of any kind so that the complex system in use may function again very quickly after the trouble has arisen.

A well-built and completely equipped laboratory with the best arrangement of rooms and the most elaborate and complete working places and apparatus will make a profound impression upon the minds of students. It will foster habits of care, give them interest in the work, and permit them to develop both themselves and the science in which they are working. It pays to spend money to get the very best that can be obtained.

In addition to all these requirements a chemical building must have offices, library, stock room, class rooms, balance rooms and other rooms which are common to the laboratories of other sciences. The variable factors which must be looked after in planning a suitable building are many indeed, and they must all be taken into consideration if one would desire to get an ideal building.

CHAPTER II

ARRANGEMENT OF INTERIORS, TYPES OF BUILDINGS

J. N. Swan

Director, Department of Chemistry, University of Mississippi

Controlling Factors. In planning a laboratory building it is generally recognized that there should be some controlling considerations in the development of floor plans. Among these the following might be mentioned:—class rooms not interfering with each other, stock rooms, located in strategic positions, and lecture rooms and large laboratories being easily accessible from the main entrance of the building. Other considerations might be named, and the question naturally arises as to how many such factors must be taken into account and what relative importance is to be given to each. It is important, for example, to make a proper decision as to the number of entrances which the building should have, but this is not so important that it should take precedence over all other questions.

It is proposed here to discuss briefly some of the details which must be kept in mind in making the floor plans for a chemical laboratory. Some of these titles may seem very simple, but the simple things must be kept in mind in any such discussion. At the same time, it is impossible to discuss everything which might be considered in such an undertaking. Some arrangements are purely local and must necessarily vary. In fact, even the major considerations here enumerated will vary in accordance with the size, location and purpose of the building, nevertheless, it is the part of wisdom for every planner to consider the items discussed in the following pages.

Visualizing Dimensions. It is important that rooms be visualized from three dimensions, the length, the width, and the

height. It is sometimes quite difficult to visualize the vertical dimension. The floor plans should also be of sufficient size, as previously indicated, not less than ¼ in. to 1 ft. scale, and possibly ½ in. to 1 ft. scale. There are available to-day catalogues of practically all materials required in a chemical laboratory, and

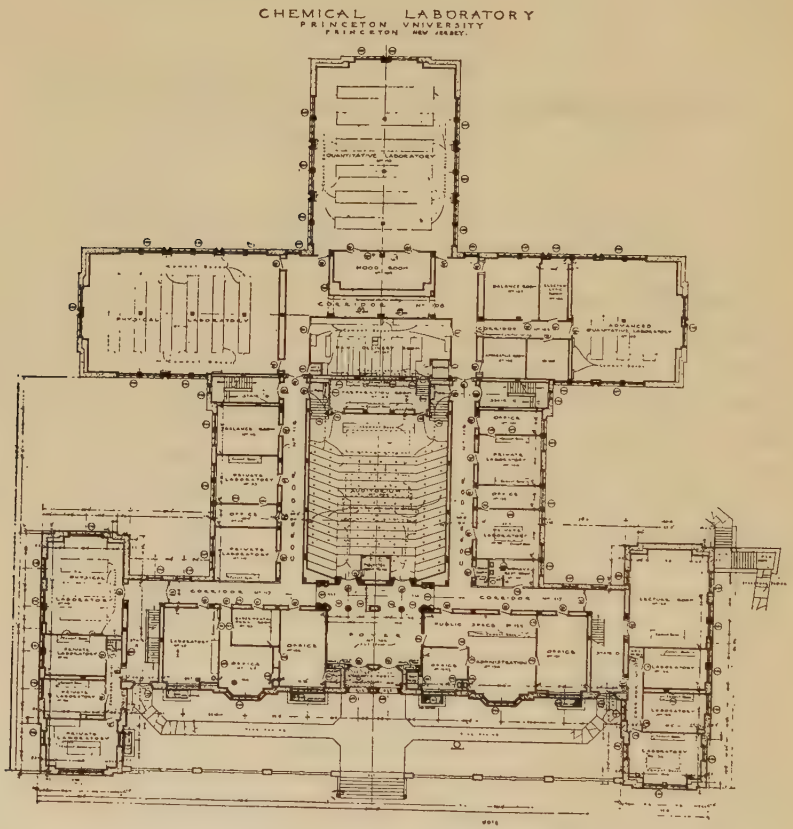

Fig. 1. First Floor Plan, Princeton University.

by means of a judicious selection from these catalogues, it is entirely possible to secure a very clear idea of what the vertical proportion of a laboratory will be. This phase is highly important, as it affects the visibility from the standpoint of the instructor, it affects the utility of the laboratory and it concerns aisle spaces convenient for moving in large pieces of equipment, and many other phases.

Location of Stock Rooms. Because it is the center of activity and serves every worker in a chemical laboratory, careful attention should be devoted to the proper placing of the stock room. It should be located so near the working laboratory that a minimum of time and distance will be used in obtaining needed sup-

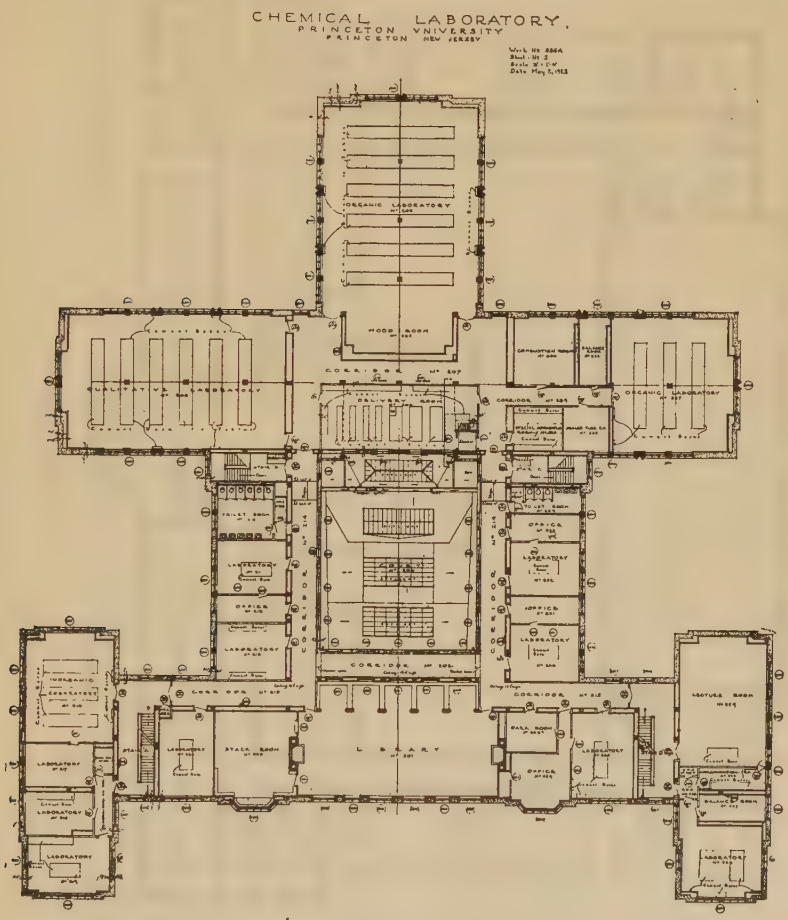

Fig. 2. Second Floor Plan, Princeton University.

plies. In large laboratories there will be stock rooms on different floors and sometimes more than one such room on a given floor, but in smaller laboratories all may be served from a single stock room window. The stock rooms must be so large, conveniently

arranged and fully equipped that they will completely serve their purpose and serve it promptly.

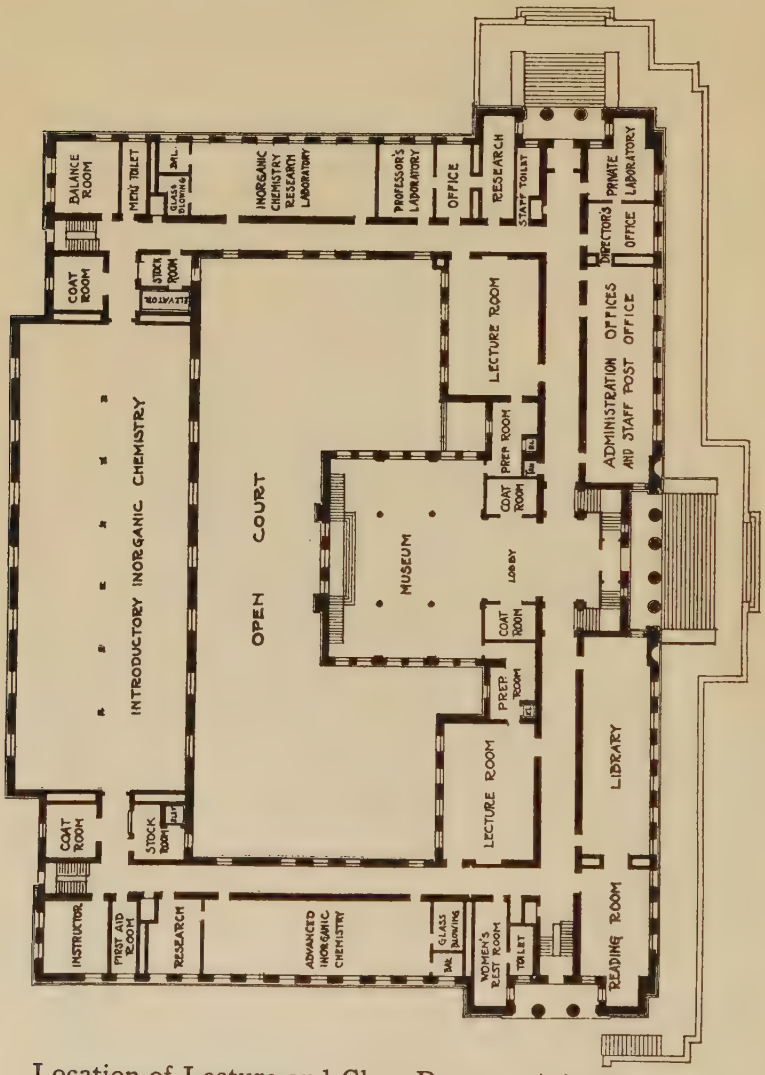

Fig. 3. First Floor Plan, Cornell University.

Location of Lecture and Class Rooms. A large proportion of the students who enter lecture and class rooms come to the building for that purpose alone, going directly to the class room and leaving the building when the class exercise is over. For this reason it is desirable to make access to these rooms as easy

as possible from the main entrances to the building. There must be quiz and consultation rooms where laboratory sections may easily be taken for conference or quiz, and both these rooms and class rooms are needed in different parts of the building. The large lecture room should preferably, though not necessarily, be on the same floor with the main stock room and reasonably adjacent to it. Lecture and class rooms should be located with relation to lighting from the outside unless dependence is placed wholly upon artificial light. If it does not interfere with more important considerations, it is desirable that recitation rooms and offices be placed on the west side of the building while analytical laboratory rooms are best placed on the north side.

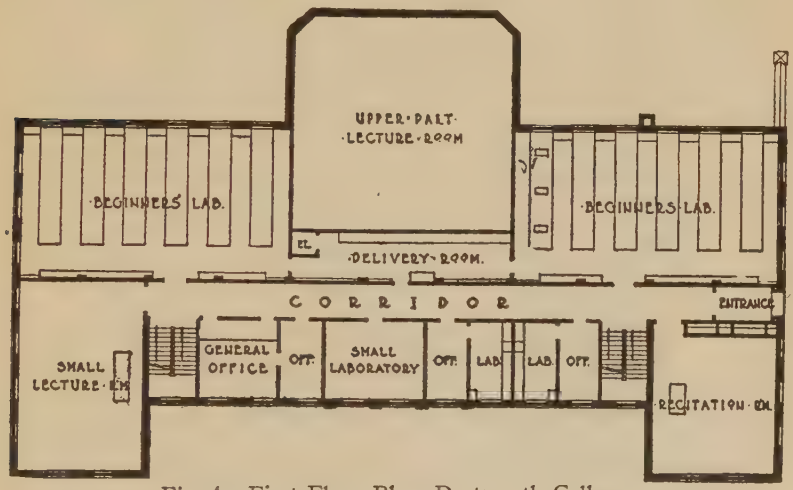

Fig. 4. First Floor Plan, Dartmouth College.

Preparation Room. Preparation rooms should be adjacent to each lecture room and may be located back of the lecture table wall, or at the side of the lecture room. If movable tables on tracks are used, the side room is more readily accessible. In a number of cases, the preparation room has been located under the raised seats at the rear of the lecture room but this is quite inconvenient.

Location of Large and Small Laboratories. Access to large laboratories, or groups of smaller laboratories, should be made as direct as possible so that the students passing to them will not disturb other users of the building. It is to be kept in mind

that they must have easy access to the stock room or one of its branches. If large laboratories are over fifty feet in length at least two exits should be provided. It is better not to place large laboratories on the upper floors if this may be avoided. Adequate cloak rooms should be provided, conveniently located near the laboratories. Fire exits must be provided in compliance with local regulations.

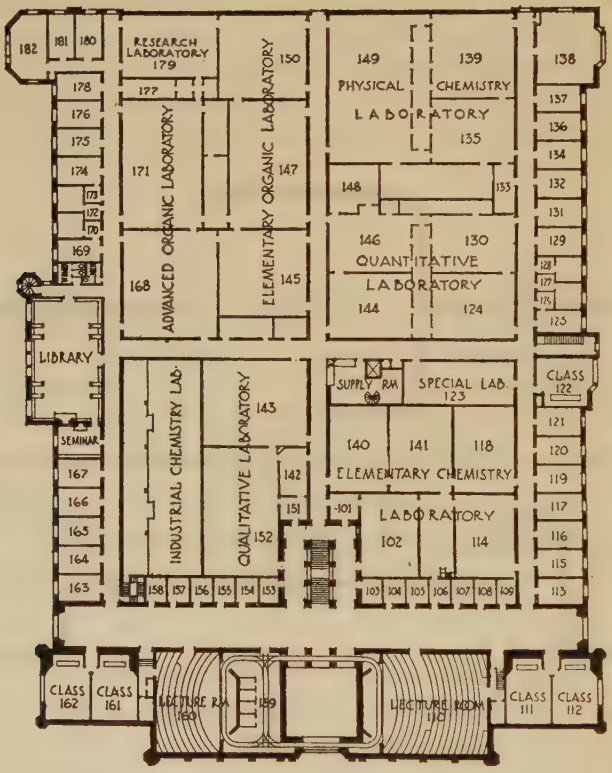

Fig. 5. Sterling Laboratory, Yale University.

Some prefer dividing large laboratories by partitions into smaller rooms, each accommodating only thirty students at a time. A building which is to take care of a large number of students will necessarily have many such rooms if this plan is followed. This does not represent the usual practice of most chemical laboratories, and is not economical as it involves extra cost if one side of the building is divided into many small

laboratories. A possibility exists here of dividing the larger laboratory into groups by means of cases and hoods, thus localizing the work that is being carried on, while allowing the entire floor to remain under the supervision of the professor, with an assistant in charge of each group. In general, a large laboratory is desirable from the vantage point of plumbing, lighting and ventilation, as well as from the improvement in grade of work, even though it requires the services of several instructors, as is the rule in General Chemistry.

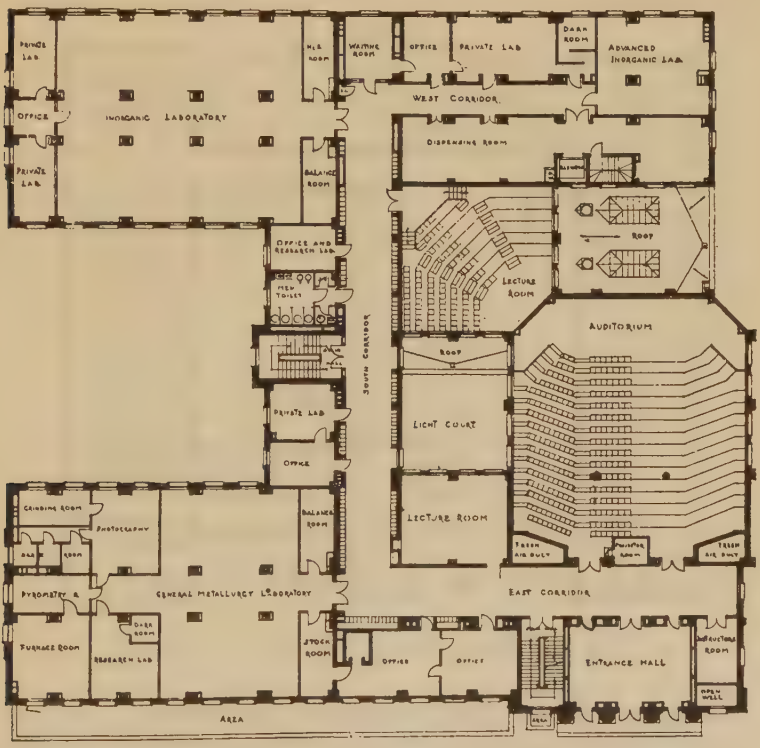

Fig. 6. First Floor Plan, University of Iowa.

It follows naturally that rooms for advanced courses and for comparatively few workers may be located in remote parts of the building or on the upper floors, yet offices of the head of the department should be in an easily accessible place. A great many students must consult the professor in charge, and there are also incidents where frequent outside connections are

handled by him. Adequate and convenient space should be provided for each professor and, if possible, his private laboratory should be adjacent to his office.

Obnoxious Rooms. There are always some rooms about a laboratory that are noisy. Such rooms as shops, unpacking rooms, or rooms where machinery is operated, should be located where they will cause the least disturbance. There are available also various efficient methods of sound-proofing such rooms to reduce the noise factor when they cannot be located in an isolated position.

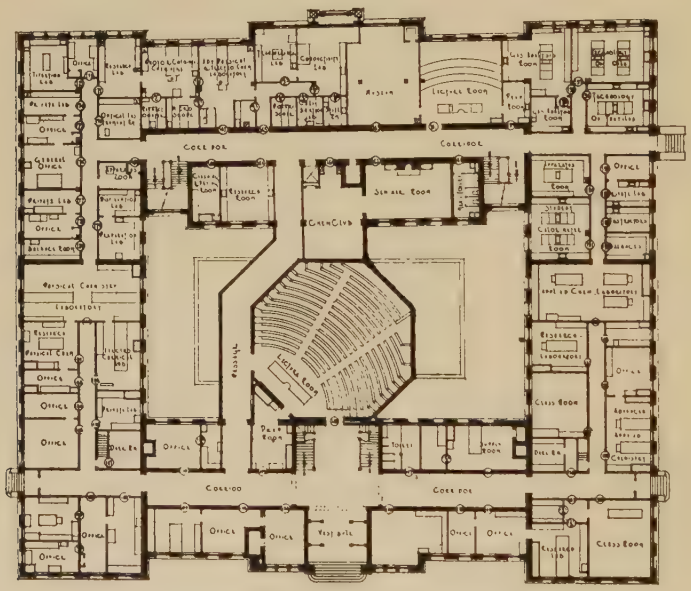

Fig. 7. First Floor Plan, University of Illinois.

Location of Rooms for Branches of the Subject. The rooms devoted to a given branch of chemistry, the offices and private laboratories of the instructors, should, if possible, be with the laboratories, adjunct rooms, balance rooms, etc., which are to be so arranged as to make a complete whole for that branch, and are best located on the same floor. The rooms on one floor must be correlated with the rooms on the floors above and below, to simplify and lessen the cost of the piping and leads. Balance rooms should be readily accessible to the laboratories which

they serve. Storage rooms for bulk apparatus or little-used apparatus may be located in out-of-the-way corners. The greatest simplicity of arrangement compatible with maximum of service should be the guiding thought in the planning of the relative position of rooms in any given section.

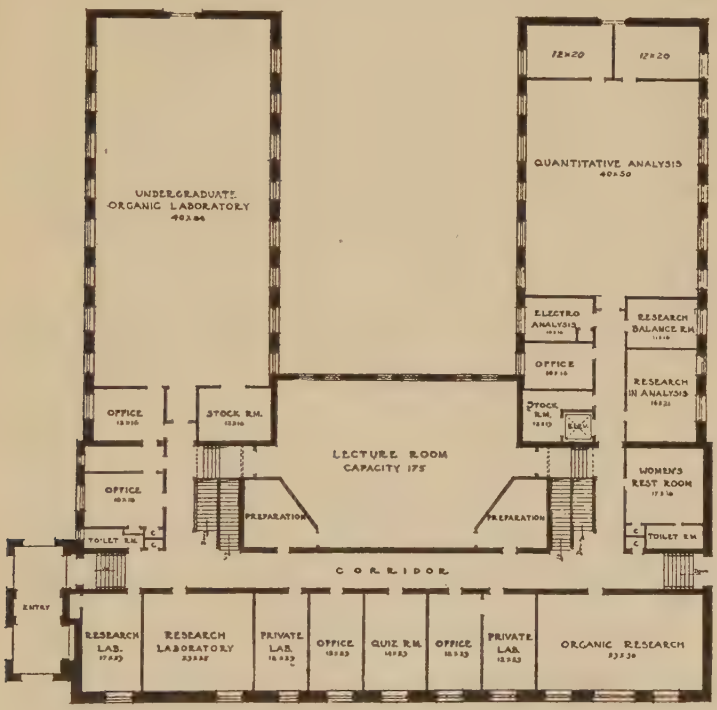

Fig. 8. First Floor Plan, Johns Hopkins University.

In developing the plans of a laboratory, there should be close cooperation between the one responsible for the plans and his colleagues, but the idiosyncrasies of a member of the staff should not be allowed to introduce unwise construction, since a building far outlasts a teaching force. To eliminate this difficulty, a committee should be established, consisting of the chemical faculty, or selected members of the faculty, the engineer, the equipment engineer, if one is selected, and the architect. This committee should decide all factors in the planning and location of the several departments.

Sizes of Rooms. There is a marked diversity of opinion as to what rooms should be provided in a chemical laboratory and possibly still greater divergence of opinion as to the proper sizes of the rooms. Given a definite amount of money for the buildings and the same work to be done in each, two heads of departments will differ much as to the number of rooms desired as well as in their size. For this reason it is almost impossible to recommend a list of rooms which should be furnished, or even a complete list from which certain rooms might be omitted in order to suit the size of the building to be erected or the money available. The rooms, again, will vary with the character of the institution. Institutions giving professional or technical courses call for arrangements which are different from those giving only academic courses.

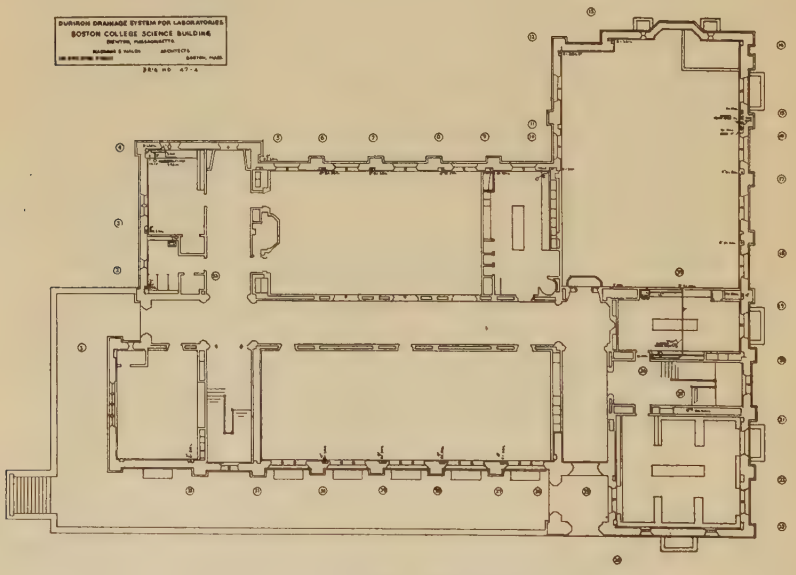

Fig. 9. Floor Plan, Boston College.

Lecture Rooms. Lecture rooms without a balcony may have a capacity of about 375 seats; with a balcony, the capacity may be increased to 500, but the distance from the lecture table to the most remote seat should not exceed 55 feet. A simple method of calculating the amount of space necessary for a given seating capacity is to multiply the seating capacity by ten and

this product will represent very closely in square feet the floor space needed for that number of seats. Thus to seat two hundred persons would require a floor space of two thousand square feet, or a room forty by fifty feet.

Class Rooms. Fifty seats are regarded as a good maximum for class rooms. Rooms of an intermediate size may prove very useful for some institutions. It is not at all necessary to have a class room for each teacher. One-half as many class rooms as teachers may not be needed even in medium-sized institutions and a much smaller proportion will suffice in large institutions. All class rooms, if lighted by daylight, should, where possible, have the windows at the left of the students as they sit in their chairs. Most class rooms need a demonstration table and space

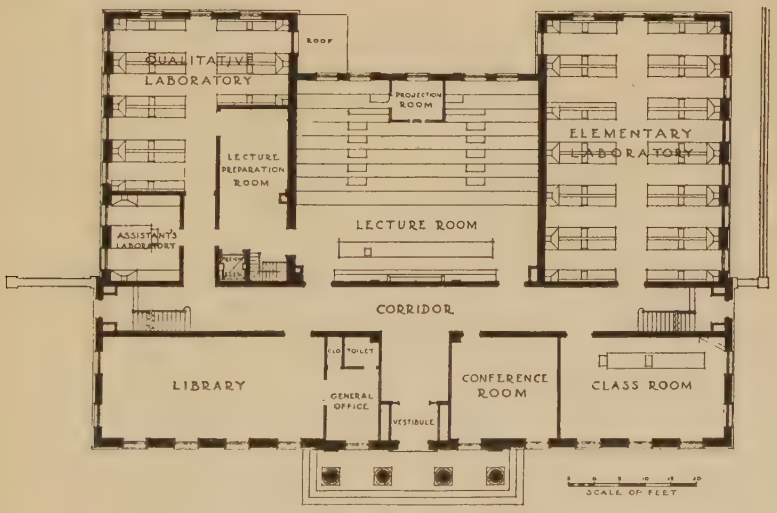

Fig. 10. First Floor Plan, Hall Laboratory, Wesleyan University.

must be provided for this in planning the room size. However, the above method of calculation includes table space as well as aisle space. Very small rooms would be somewhat crowded if ten were used as the multiplier, while in very large rooms this multiplier would be ample. Recitation rooms should be fitted with a demonstration table to enable them to be used as class rooms for special topics.

Accessibility of All Rooms. A difficulty which commonly presents itself in planning a building is that of making each room

directly accessible from the corridors and not through another room. When a building of some width is planned there are spaces which are larger than needed for specific rooms and it is but natural to cut off a part of such space and make an interior room of it. This necessitates going through the outer room to get into the inner one, a very inconvenient and often very annoying arrangement.

It is possible to place a balance room within another room without causing much difficulty, and yet, even this sometimes calls for access when it is not convenient to have the laboratory open. Another possible exception to this rule is the location of the fireproof vault for the storage of platinum or small special storage room or stock room, which is accessible only from the large stock room.

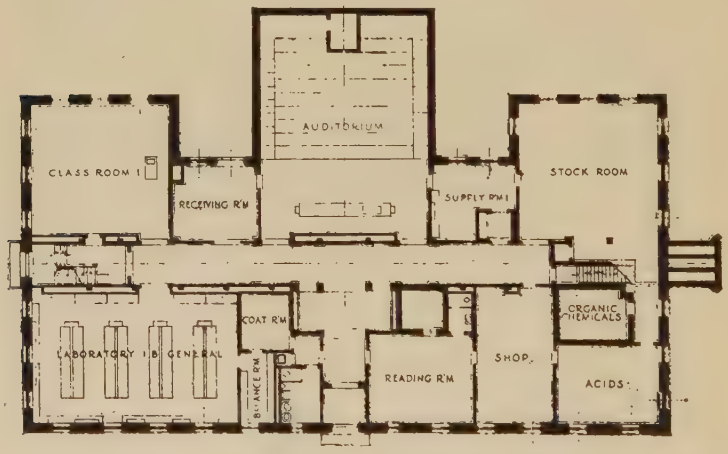

Fig. 11. First Floor Plan, Amherst College.

Sometimes a set of rooms may be located so as to open into a side corridor and this corridor is then joined to the main corridor by means of a doorway. With such a plan the side corridor may be closed and thus all of its rooms will be isolated from the main corridor. This is far better than having to pass through one room to get to another.

Simplicity of plan is most desirable. Workers in the building should be able to find other workers readily. For the guidance of visitors or students it is suggested that besides the general directory near the main entrance of the building, a

legend be placed at the head of the stairway on each floor, comprising the number of the floor, the numbers of the rooms on that floor and arrows indicating their position, and a directory of the staff and the numbers of its rooms. Additional help will be given by placing guide numbers at the corners where corridors change their direction.

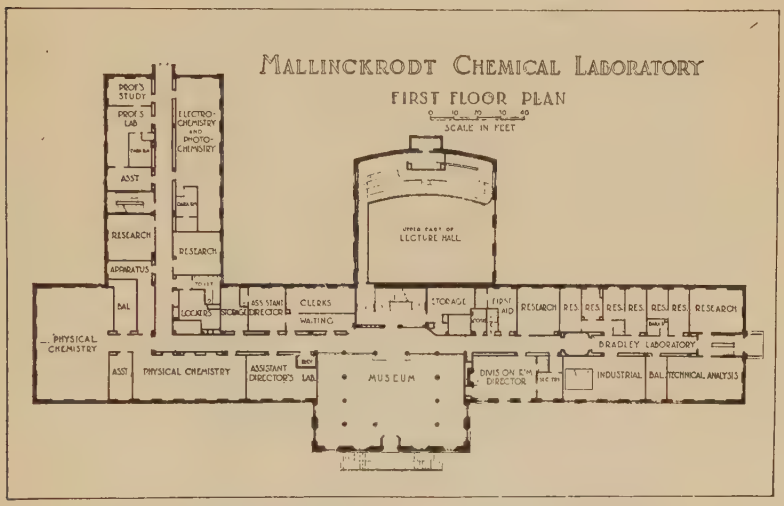

Fig. 12. Mallinckrodt Laboratory, Harvard University.

Other General Considerations. Corridors have a definite purpose to fulfill and should be planned for this service. This does not mean that they should be too narrow, but the floor plans should be arranged so that the corridors occupy a relatively small amount of space. A small number of entrances help to conserve the corridor space. In a medium-sized laboratory which uses a single front entrance, the entrance vestibule should have a fair width, say twenty feet or more. The main corridor should have a width of from eight to ten feet, but the adjoining corridors may be made somewhat narrower, from five to seven feet. If the corridors are to be used for wall cases, lockers or coat hooks, they should, of course, be given additional width.

Window Sills. The window sills in laboratories should be flush with the table tops or only a few inches above them, but should not be placed lower than this.

Plumbing and Conduits. The plumbing and conduit systems must have some influence on the proper location of the rooms for various purposes. The details for the proper correlation of these with the floor plans will be discussed in the chapter on plumbing.

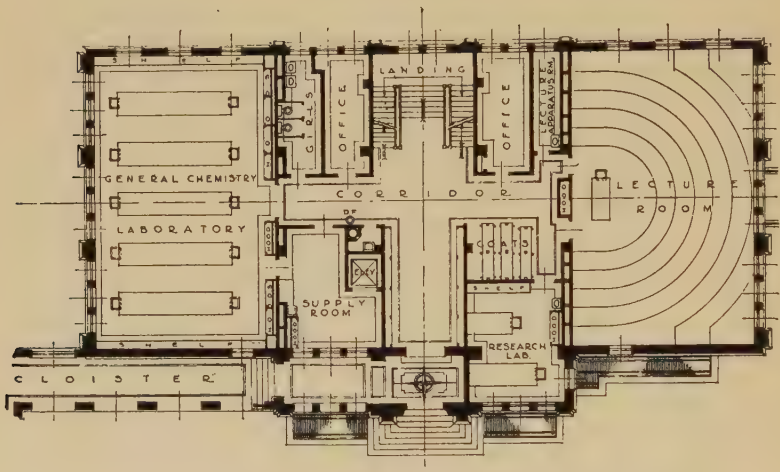

Fig. 13. Floor Plan, University of Richmond.

The Plan of the Laboratory

Other Factors. In planning a Laboratory of Chemistry, its size, shape, plan, and equipment will also be governed by other factors such as site, surroundings, climate, purposes for which the building is to be used, probability of needed extension in the near future, and the amount of money available for its construction, operation, and equipment.

Whenever possible the building should be fireproof throughout, should be provided with forced ventilation, should have ample space for library, administrative offices, and the receipt and storage of chemicals and apparatus. It should be so designed that stock rooms are conveniently accessible to the users of the building, and the various laboratories should not be made thoroughfares for passing from one part of the structure to

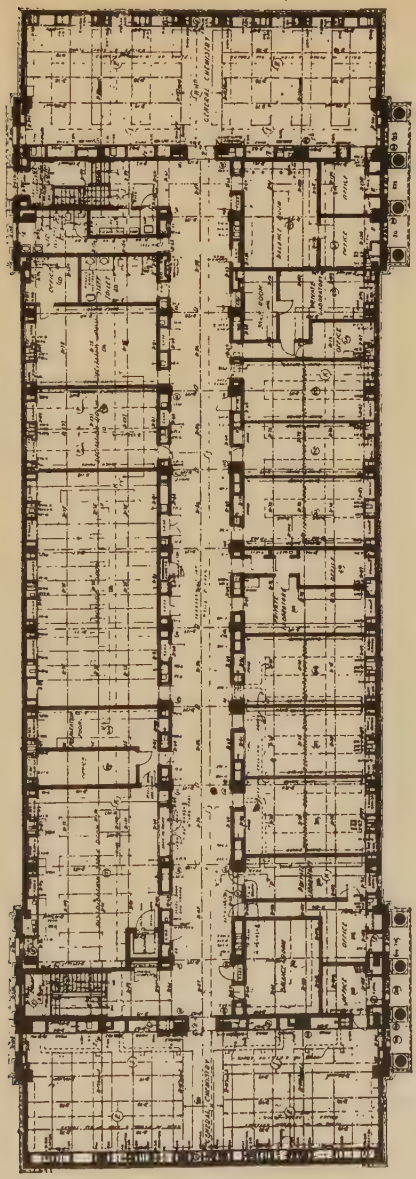

Fig. 14. Floor Plan, University of West Virginia.

another. Furthermore, the permanent equipment, plumbing, electric wiring and outlets, laboratory tables and hoods should

be of as simple and inexpensive types as will give satisfactory service.

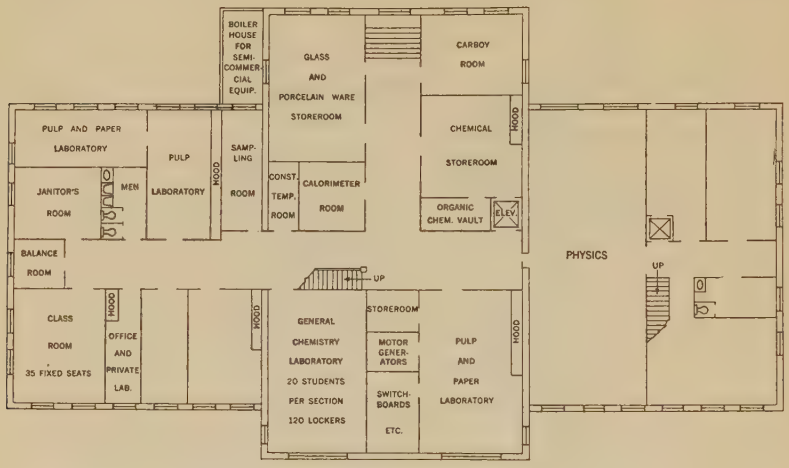

Fig. 15. Floor Plan, University of Maine.

Shape of Building. The shape of the building will depend so largely upon the factors mentioned above as to render it impossible to select any one design as superior to all others. In a hot climate a long narrow building which will permit of the free circulation of the outside air will probably be most comfortable for the users. In large cities where the site is costly, a high, compact building would probably be most feasible. Satisfactory laboratories having the shape of an **E** or an **H** have been constructed, but if it later becomes necessary to extend the building, neither of the above forms lends itself well to this purpose unless the laboratory rooms that are to be enlarged have been placed in other parts of the building than the projecting wings. The plan that most easily and most inexpensively permits of enlargement of the building is the hollow square (Fig. 16), to which two projecting extensions may be added and the ends of those extensions later connected, forming a second court. If the court is of sufficient width and is faced with light colored brick, the lighting of the rooms on the court is quite sufficient, and in fact is often better than the lighting in the rooms on the exterior of the building. If in the original design the administrative offices, lecture rooms, and stock rooms are properly located the

additions to the building of the hollow-square type need call for no interior rearrangement whatsoever. Laboratories illustrative

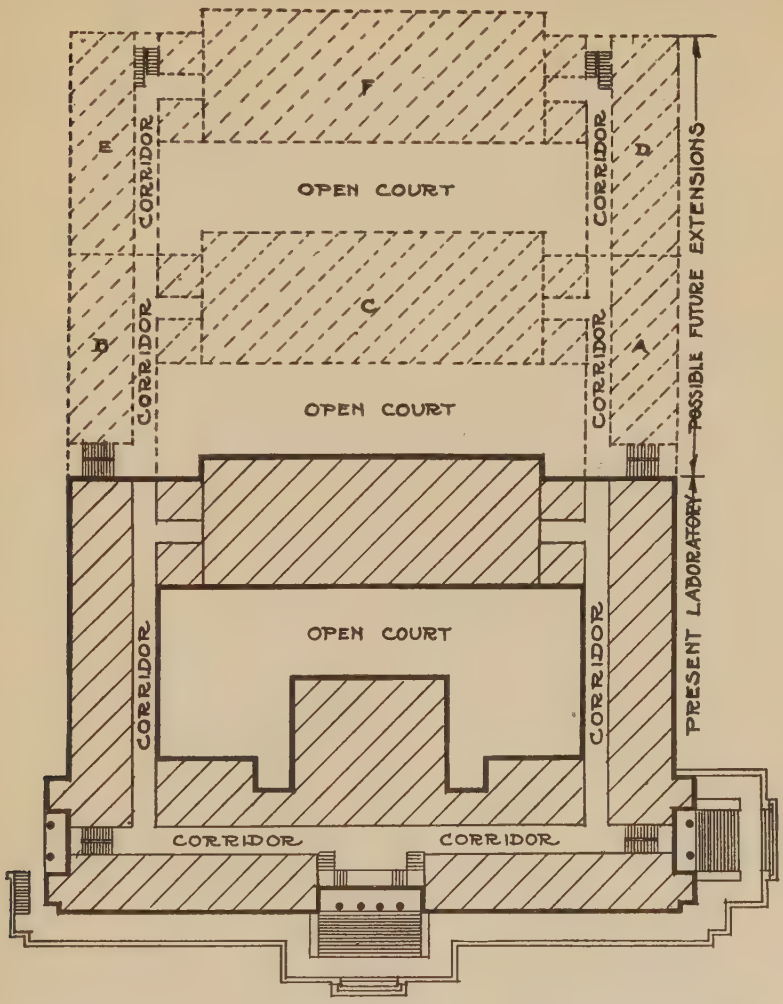

Fig. 16. Design of Building Showing Possible Future Extensions, Cornell University.

of these various shapes are shown in the sketches of chemical buildings that appear in this chapter (Figures 1 to 17).

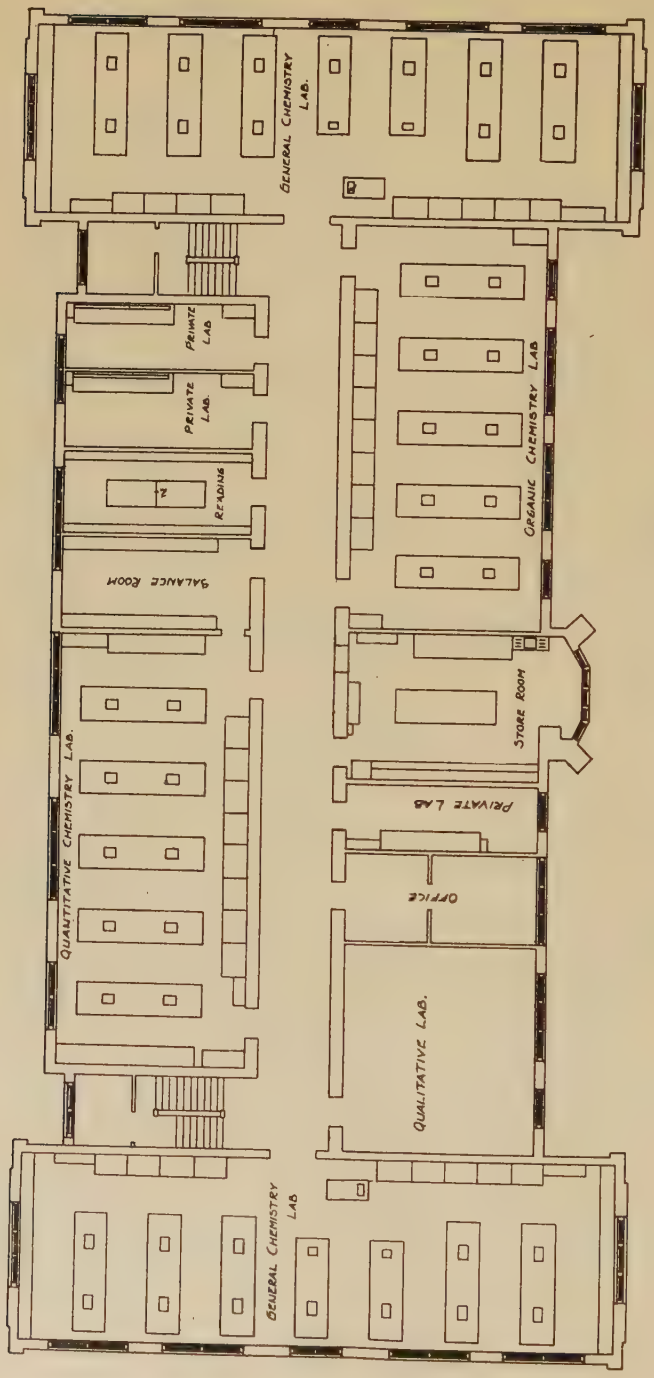

Fig. 17. Floor Plan, Muskingum College.

CHAPTER III

LOCATION AND EXTERIOR CONSTRUCTION

C. R. Hoover

Chairman, Department of Chemistry, Wesleyan University

General Considerations. The exterior of a building, designed to house a laboratory, may seem to be relatively unimportant to the prospective user of the laboratory. Its location with respect to direction and other buildings is too frequently settled before the chemical staff of an institution is consulted, and even when consulted, the scientific worker often disclaims any interest in the exterior, conscious only of his interest and the value of his advice in the arrangement of the interior. Unfortunately for him, exteriors are usually planned first, so perforce his later suggestions receive secondary consideration. It is therefore evident that cooperation of the chemist with the architect and the engineer should begin, if possible, before a new building is located or a part of a building assigned for chemical use.

All those interested in the housing of laboratory sciences must patently recognize, however, that a number of factors other than the unrelated exterior appearance and interior arrangement must be taken into consideration in determining the location and designing the exterior of a laboratory. Let us consider first some of the factors which influence location.

Location

1. **Relation to Other Buildings or Parts of Buildings.** The necessity for considering this factor arises chiefly in educational institutions and industrial plants where laboratory work is sufficiently important to justify the erection of a separate permanent building. Brief consideration of the relative merits of a laboratory in a part of a building or in a separate structure, although

previously discussed, may be in order here. Modern practice indicates an increasing tendency to provide a separate building

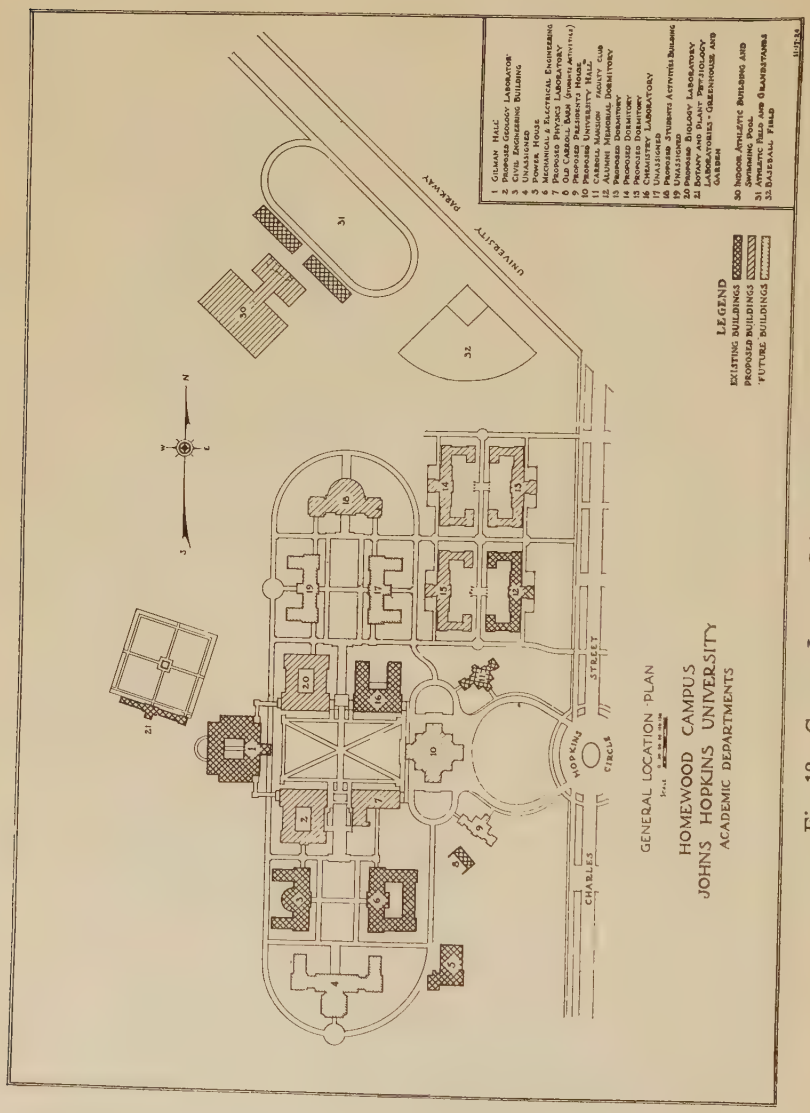

Fig. 18. Campus Layout, Johns Hopkins University.

whether for educational or industrial chemistry. Special problems of ventilation, plumbing, and lighting sharply differentiate

chemical laboratories from laboratories for other natural sciences, and from class rooms, libraries, industrial shops or offices. The lower cost per cubic foot, made possible by the erection of a large building, a portion of which is to be used as a laboratory, is offset by the difficulties of effective utilization of space, location of plumbing and wiring, and the annoyance of individuals and the injury to materials caused by accidental escape of odoriferous and corrosive gases.

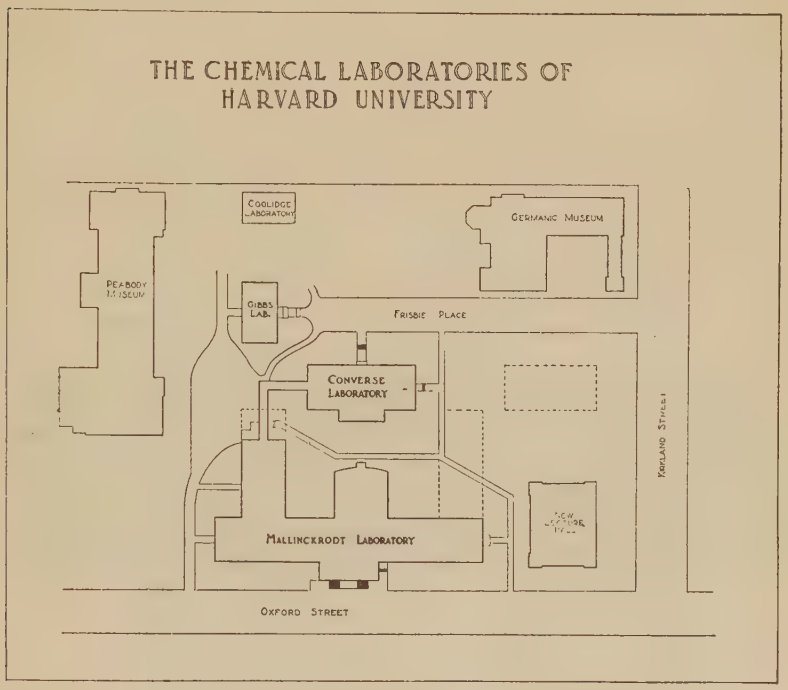

Fig. 19. Campus Layout, Harvard University.

A comprehensive plan which determines the location and relation of a number of buildings is highly desirable from a number of standpoints. Such general considerations as topography and accessibility to other buildings, departments of the institution, or highways and transportation facilities are of considerable importance. In industry, administration offices and laboratories are generally considered the nerve center of the plant, and are given a central location, readily accessible from all parts. Since a laboratory has more connection with the plant

than with the general public, it is usually located further from the natural lines of approach than office buildings. In any type of institution, provision should be made for the delivery of supplies to the rear entrance of a laboratory, parking space for automobiles, and convenient walks for pedestrians. Considerable unnecessary expense can be avoided if the need of supplying a laboratory with electricity, steam, water, gas, etc., be kept in mind in determining its location or laying conduits, heating tunnels, and supply mains. In educational institutions, the common needs of the natural sciences suggest a group of laboratories and museums in one section or unit.

Fig. 20. Campus Layout, University of Richmond.
Chemical Laboratory to Right.

In planning a group or a unit, the needs of all buildings proposed must be carefully considered, particularly the highly specialized departments, and the design arrived at should adapt itself to the requirements of the most highly specialized, yet allow sufficient flexibility to accommodate the less specialized. It should be borne in mind, however, that a comprehensive plan, which determines the shape and dimensions of several buildings, may have the fatal disadvantage of limiting or prohibiting the future extension and improvement of these buildings. General plans are most successful when applied to a group or a unit which can be erected in a relatively short time. It is impossible

for one generation to anticipate adequately the needs of the next, and the fundamental principle of progress and development should always be kept in mind. Examples of good educational arrangements are shown in Figures 18 to 20.

2. **Natural Lighting.** Efficient natural lighting is an important factor in determining the exterior design of a building. No one tendency has been more noticeable in recent building construction than the increased utilization of sunlight—the increased use of glass for decorative and utilitarian purposes. Laboratory work is aided by these developments; in general, industry and business have been more favored than educational institutions. While a building entirely of glass and steel does not yet seem necessary for the laboratory worker, recent European designs of this nature establish a limiting type which is gradually being approached. For many purposes a maximum amount of north light is not only desirable but necessary in the north temperate zone, and the intense but more constant south light is probably more valuable than the widely varying illumination from east and west. Hence, it is generally preferable to place a laboratory with its long axis in an east and west direction. Exterior materials and location as well as the dimensions of a building have considerable effect on the natural lighting, and will be discussed later. In general, it is found that two parallel buildings should be faced with light-colored brick if closer than 70 feet.

3. **Future Extension.** In many cases it is not possible or advisable to erect the entire projected structure at one time. Industries, schools, and colleges frequently build one section or unit of a laboratory, and add to it later. A constantly increasing interest in the science of chemistry makes it poor policy to erect a building to meet present needs and make no provision for later extension. The location chosen must, therefore, allow for future additions without interference with other buildings. Considerable open space, adjoining a laboratory, should be available for the erection of small, more or less temporary buildings for special investigations, the carrying out of weathering and sunlight tests, storage of bulky supplies, especially inflammable and poisonous materials, gas holders, and oil tanks. These needs should also be kept in mind in planning the shape and dimensions of a laboratory as well as when determining its location.

4. **Noise.** Noise is generally regarded as less objectionable for laboratories than for offices, libraries, and class rooms, but it is, nevertheless, a handicap in most laboratory work. Vibrations from street cars or trucks, and from heavy machine operations in an industrial plant may interfere seriously with the use of balances and other equipment. Electrical instruments are frequently disturbed by passing vehicles and by miscellaneous electrical discharges. Since these more serious disturbances are usually associated with noise, it is evident that it is highly desirable to choose a quiet location for a laboratory.

5. **Ventilation.** Pure air, free from dust and objectionable vapors, is essential to most laboratory processes. Chemistry was formerly supposed to thrive amid smoke, flame, poisons, and poor ventilation, but this environment is incompatible with the exact science it is to-day. Such objectionable products as are necessarily employed in a modern laboratory are under control, and this control requires large volumes of pure, fresh air. When all ventilating fans are operating, a modern laboratory draws in from outside every few minutes a volume of air equal to its cubic capacity, and appreciable quantities of dust and objectionable vapors may be introduced in this way. Buildings requiring less frequent changes of air, contrary to the usual impression, are, therefore, less dependent upon pure, outside air than a chemical laboratory. While it is possible to purify air drawn into a building, operating costs can be very much lessened if the laboratory is located some distance from sources of dust, smoke, and fumes of any kind. Green grass, shrubs, and trees are useful as well as ornamental as a setting for a chemical building.

Exterior Design

1. **General.** In planning simple types of buildings, the combination of interior arrangement and exterior design is usually entrusted to the general architect, but for the highly specialized type of construction demanded in a chemical laboratory, constant and effective cooperation of architect and chemist is necessary. As a guiding principle in the preparation of plans for the exterior as well as the interior of a chemical laboratory, we should accept the simple proposition that a laboratory is a structure designed to provide space in the interior for scientific work. It may serve

other functions, but use is its primary function. This is in accord with the dominant motives of modern building, which are largely utilitarian. Architects here and abroad have cooperated in

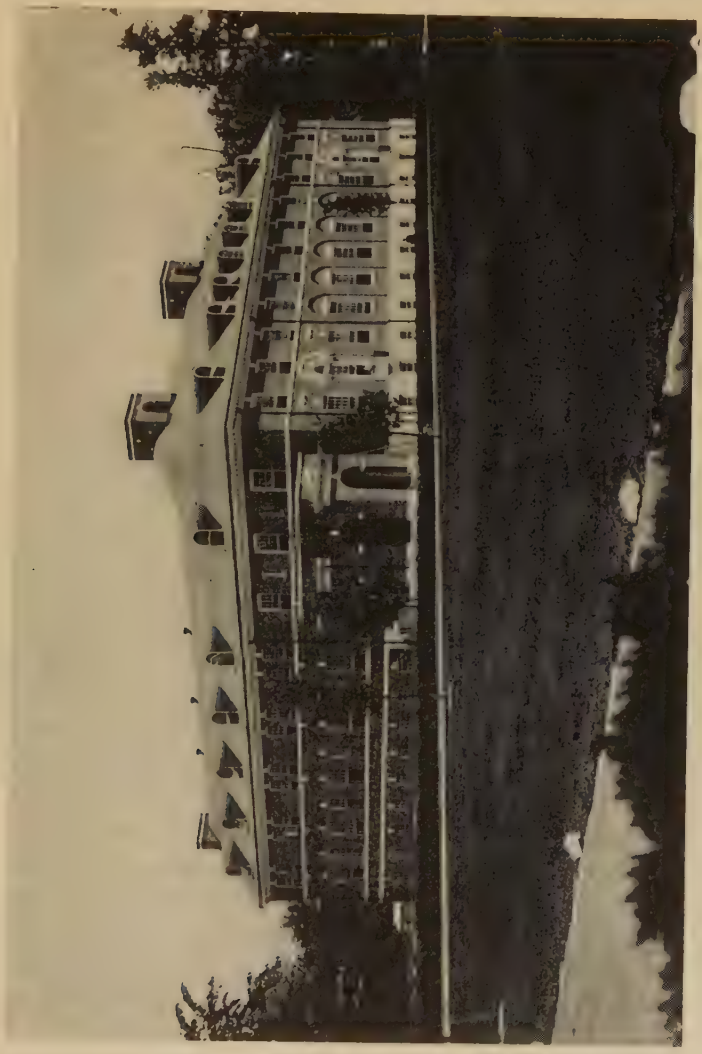

Fig. 21. Chemical Laboratory, Johns Hopkins University.

developing commercial and industrial exteriors of considerable beauty. Public school design has also improved, especially in lighting, ventilation, and safety provision, so that the needs of

class room instruction are frequently well provided for, but the special needs of the natural sciences have not been so effectively dealt with, and school officials and administrators might well consult more freely with their science teachers or with others experienced in laboratory construction before completing plans for secondary school buildings. Chemists in manufacturing plants and in small colleges probably suffer most from inefficient exterior design. Some administrative officers and architects still accept the dictum of a generation ago—"Any building is good enough for science." Several colleges still house their departments of chemistry in Gothic monstrosities, with narrow, deep recessed windows, and high ceilinged, unventilated rooms; and industrial laboratories are frequently found in the dark end of a shop building where dust, vibration, and noise make satisfactory work impossible.

Fig. 22. Nichols Building for Chemistry, New York University.

If we accept the general guiding principle that the appearance of a laboratory should, as far as possible, be made to accord with the interior arrangement, one should first consider the interior arrangement in making plans for a building. While actual construction cannot proceed in this order, a logical method of designing a laboratory is to plan it about the unit of space required for the average laboratory worker. A convenient unit of this nature is determined by the width of an aisle and two adjoining work tables. Such a unit is found to vary in width in different laboratories from 8½ to 10 feet, and practically all existing laboratories can be resolved into such units, although they

may not have been in the mind of the designer when plans were begun. Two such units define a convenient, small research laboratory or office. These unit dimensions accord well with modern construction involving steel or concrete supporting members, regular window locations, and admit of pleasing exterior and interior architectural treatment. Future additions can be planned in terms of these units, enabling one to estimate readily the space, equipment, and supply lines required for a given number of laboratory workers.

Fig. 23. Jenkins Laboratory, Loyola College, Baltimore, Md.

Many of the considerations discussed in connection with the location of a laboratory apply to the choice of a style of architecture. Similarity of treatment of a group of educational buildings or an industrial plant has a natural appeal, but, as previously pointed out, unless a comprehensive plan can be carried through in a reasonable time, a heavy handicap is placed on later additions and extensions, and future workers may be compelled to accommodate themselves to inefficient and poorly arranged interiors in order to continue a certain type of architecture or material of construction. Architects will probably be most successful in satisfying the needs of industrial and educational

clients if similarity of treatment, not uniformity of design, be employed, and this treatment be confined to a unit of a plant or a group of buildings the completion of which is assured within a reasonable time.

2. **Dimensions and Proportions.** The factors which fix these points are largely the number of workers to be housed and the amount of money to be expended. From the standpoint of economy the more nearly the exterior of a building resembles a cube, the more successful the building. Hence, a one-story building is infrequently constructed. The one-story, saw-toothed-roof construction has several advantages such as good natural lighting and ventilation, a maximum of remodeling and repartitioning flexibility, relatively cheap floor and wall construction, and absence of waste space under the roof. In the minds of most unprejudiced observers, however, these advantages apply more fully to this type of construction when used in industrial units than when applied to laboratory construction. Location of supply and waste-pipes, air ducts and wiring conduits, which in one-story construction are relatively long and expensive, demand additional excavation and increased cost of floor construction. Artificial ventilation and heating are handicapped by the nature of the roof construction and the position of exposed glass, since side-windows are usually absent in this type of construction. The psychological effect on some workers seems to be depressing, perhaps because of the inability to relieve eye fatigue by momentarily looking at a distant object or because we are more accustomed to horizontal than vertical natural illumination.

The waste space in a building usually decreases as the number of floors increases. This is largely due to the demands of exterior appearance. Low buildings certainly offer less opportunity for conventional architectural treatment, and the tendency is to increase ceiling heights and provide cornice or roof construction which adds to the apparent height, and, of course, to the cost. Consideration of safety and accessibility have recently caused notable changes in school, and to a less extent in shop, construction, and pleasing examples of one-story buildings are now quite common. However, before adopting for a laboratory a type of construction which has great possibilities but at the same time may not be suited for the particular type of work to be carried on, it is suggested that the builder spend some time

Fig. 24. Chemical Laboratory, University of Illinois.

in one of the excellent existing examples of this type of construction, or consult with those who have worked for some time in such buildings.

In sharp contrast to the use of one-story laboratory construction is the sky-scraper, necessarily adopted by some large urban universities and voluntarily adopted by at least one university which occupies a moderately large campus. A discussion of the relative merits of buildings depending upon elevators and those using stairways is not in place here, as few architects are likely to be confronted with this problem, but for large departments or a number of related departments, the obvious advantages of compactness and accessibility, made possible by the modern elevator, offer interesting possibilities. The wide variety of apparatus employed in a chemical laboratory necessitating, for example, solid, heavy foundations for certain purposes, and natural, vertical illumination for others; adequate storage space and rooms for ventilating machinery, switchboards, and the maintenance of constant temperatures, the difficulties of distributing liquids and gases over great vertical distances, the dangers resulting from accidents to ventilating equipment and elevators, combine to suggest to the prospective builder that a conservative decision in favor of from two to four stories, with basement and attic, will probably prove most satisfactory from the standpoint of efficient interior arrangement and exterior appearance.

3. **Structural and Applied Ornamentation.** It is probably unnecessary to point out that one exterior wall of a laboratory should be considered the facade, and that the architect should be allowed more freedom with this portion of the exterior. This concession by the chemist is not ordinarily a difficult one to grant, for it is relatively easy to add certain conservative decorations without interfering with the interior arrangement, since offices, class rooms, and small laboratories of flexible size and window arrangement are naturally grouped near the front entrance, while large laboratories and lecture halls—in general, specialized construction—are found on the sides and in the rear. The addition of columns, pilasters, and cornices, and the employment of recesses and roof gables interfere less with the use of these smaller and less specialized rooms than with rooms accommodating a large number of workers. Simplicity of treatment of the facade of a laboratory is in keeping with the prac-

tical, democratic science of chemistry. It is probable that no laboratory is so completely equipped and so well manned that its

Fig. 25. Mallinckrodt Laboratory, Harvard University.

occupants do not prefer additional interior equipment or technical assistants to decorative tablets, pilasters, niches, porte-cochères, and balustrades. The laboratory, like the hospital,

appeals most strongly through the service it can render, and its appearance is pleasing when its fitness for this service is mani-

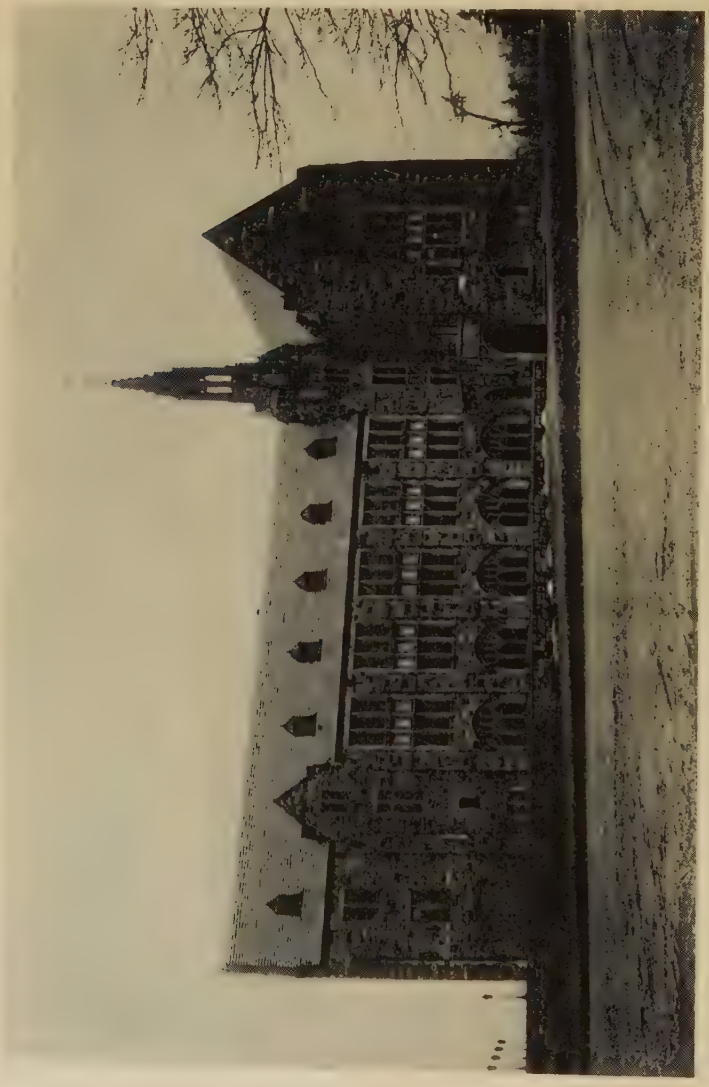

Fig. 26. Chemical Laboratory, Boston College.

fest in its exterior. The exterior appearance of a laboratory, whether in an industrial plant or an educational institution, should contribute to the respect of the casual visitor for the precision,

neatness, and broad-minded solidarity of science; it should hold the respect of the scientific visitor and occupant because of its unobtrusive but satisfactory exterior as well as because of its adequate equipment. Gaudy decoration, sensational and transitory ornamentation, colored marbles and gargoyles do not seem to be in keeping with the science of chemistry, although the popular fancy may connect it with gaudy dyes, glowing furnaces, and lustrous new metals. Strong, firm lines of roof or column, wide, regular expanses of glass, and ample doorways, are common devices that fittingly express the spirit of a chemical laboratory. Some external decorations that have been appropriately employed on laboratory facades are panels bearing names of famous chemists, alchemical and modern symbols for elements, names of elements, designs of familiar or historical chemical appliances, statues of eminent chemists, and a few symbolic friezes, representing industry, science, and art.

Exterior Materials

Brick. In keeping with the nature of laboratory processes, exterior building materials are, in general, permanent and refractory. Brick is most commonly used and is well adapted to this type of construction as it is flexible and therefore easy to adapt to spaces between windows and for the provision of space required by ventilating ducts and pipe chases. Brick is obtainable in various colors and, when combined with stone or terra cotta trim, a pleasing and practical exterior is the result. The question of the relative appearance of pressed, wire-cut, sand, and water-struck brick is one that can properly be left to the general architect, but the relative porosity is a property which affects, not only the exterior appearance but the condition of the interior walls, and consequently the use of the building. When porous brick is used, especially if the exterior walls are of brick throughout, special precautions should be taken to prevent water from coming through the walls and also to prevent efflorescence; that is, discoloration due to the deposition of white salts on the surface of the brick. Efflorescence is increased by porosity of mortar as well as of brick. It is naturally most pronounced on the side of a building most exposed to sunlight. By careful mason work it can be minimized even when porous bricks are

used. If not eliminated during construction it can be prevented by surface treatment with mineral oils or hot paraffin. The chemist interested in the exterior appearance of his laboratory should carefully consider the architect's specifications for mason work.

Stone. Stone is used for exterior walls more frequently than any material other than brick; gray limestone or light gray or brown sandstone being the most popular varieties. In general, stone construction is more expensive than brick. Light colored building stone is usually preferable because of the larger reflection of light around the windows. Marble and granite have had limited use as a material for exterior wall construction, being used chiefly as trimming for other materials. From the standpoint of the chemist, marble or other light colored window sills are objectionably delicate. A combination exterior and interior window sill of soapstone or slate is a very serviceable arrangement.

Other Materials. Artificial stone and concrete are useful and valuable materials for laboratory exteriors, especially in industry, and a combination of brick or terra cotta with smooth or stucco-finished concrete may be made very pleasing in appearance. For small, detached laboratories, more or less temporary, asbestos wood and protected metal, such as Robinson process metal, may be used with satisfaction. Wood, although very commendable from the standpoint of cheapness, is probably the least desirable material for exterior use.

Roofs. Roof materials vary with the shape and pitch of the roof. Nearly flat surfaces are commonly covered with some combination of tar and other inert material. The use of exposed tar paper and similar composition roofing is undesirable on a chemical laboratory. If a flat roof is accessible to laboratory workers, it is well to provide decks or walks of some protective material, as such a roof is frequently employed as an outdoor laboratory. The choice of material for sloping roofs may vary somewhat with the climate. Slate, tile, asbestos wood, sheet copper, and tinned iron are employed, the first mentioned being used most. Water conductors and flashings of sheet copper are most commonly used, and are preferable to tinned iron, but in the vicinity of outlets from chemical hoods, corrosion is so marked that lead flashings and gutters are preferable.

Building Construction and Interior Materials

Types of Construction. It has been pointed out in preceding pages that temporary buildings are not suitable for chemical laboratories even when the amount of money available is limited and the need of considerable space urgent. It is better to use permanent fireproof materials for a unit or part of a laboratory than to handicap all workers by dust, vibration, and risk of loss of equipment by fire. Chemists will remember that several years ago there seemed to be an epidemic of fires in chemical laboratories which served to emphasize the exceptional risk of housing chemical equipment and supplies in buildings partly or entirely constructed of combustible materials. It therefore seems necessary to discuss only permanent types of construction. This discussion will be very brief as regards supporting framework, as this is well standardized in building practice, but a few guiding principles may be useful to the chemist in his consultation with the general architect.

Foundations and Footings. If the contractor is conscientious or inspection by the architect is adequate, the chemist can contribute little to this part of the building. But because of his special interest as the user of the structure and because of his training in observation, his advice as to subsoil properties, location of heavy equipment, and avoidance of vibration is frequently valuable. Contractors and architects too frequently think that the basement of a laboratory is to be used in the same way as the basement of an office building or residence; that is, to house machinery and provide dead storage. Basement floors and all walls below grade should be waterproofed, preferably by a continuous sheet of waterproof membrane imbedded in the masonry. Tile drainage should be provided around the outside of the footings, and if filling material is used around and under the footings, it should not be compressible or so porous as to allow surface water to wash away subsoil. Well-tamped stone concrete of proper proportions is almost exclusively used as material for the subgrade construction and is, of course, a most important material throughout the whole of a permanent building. Waterproofing compounds, integral and surface hardeners, and materials added to increase the rate of setting or prevent freezing may be used with satisfaction in this as well as in various other

parts of a building, but inevitable cracks in walls and floors make it very difficult to prevent the penetration of all moisture below grade by integral waterproofing.

Frame Construction. Various combinations of concrete and iron or steel are used for the supporting frame of the building. Exposed structural steel work, much used in factory construction, is not generally recommended for use in a building where appreciable concentrations of corrosive gases and vapors are so frequently present. A properly designed steel frame, encased in metal-caging-reinforced concrete, at least two inches thick at the extreme edges of flanges, provides a type of construction frequently used. Other materials for the protection of structural steel are well known to architects and engineers and are in general satisfactory to the chemist. Reinforced concrete structural framing is considered by some to be cheaper than steel and concrete, and this combination is widely used in laboratory construction.

Wood Framing. Slow-burning mill construction, that is, a supporting frame of heavy wood, is not without advantage in laboratory construction. It is cheaper in most places and the damage from a small or localized fire is generally less serious than with exposed or partly protected steel framing.

Ceilings

Concrete. The occupant of a laboratory is especially interested in the surface of ceiling, walls, and floors. Concrete construction adapts itself well to his demands. The forming of a ceiling of concrete is an attractively simple method and one that is satisfactorily applied in factory construction by using wooden forms, but it is almost impossible to secure a smooth surface by this method. Steel forms—pan construction—have been used in several laboratories and a satisfactory surface obtained. If white cement and sand are used, a light-colored ceiling which readily reflects light is secured. Concrete surfaces are sometimes finished with a wash or spray of neat cement or a rich mixture of cement and fine sand. The surface of cast cement is usually "stoned" with a coarse abrasive if it is to serve as the finished ceiling, and in this way grain figures and joint marks are removed. If the stoning process is sufficiently thorough, a monolithic ceiling or wall of excellent appearance may be secured.

When ordinary paint is applied to concrete surfaces, the irregularities are partly concealed but the paint frequently adheres poorly. Special cement paints behave better and find considerable application in laboratory construction. A number of laboratory builders prefer a more finished appearing ceiling than that obtained by exposed concrete, listing as objections irregular surface, dusting under the action of laboratory gases, porosity and poor light reflection.

Plaster Ceilings. As the first method of improving the surface of poured concrete we consider plaster. In order to secure good adhesion of plaster, it is necessary to treat the concrete with foundation paints or bonding materials, and the coat or coats of plaster should be as thin as possible so as to be continuous and cover irregularities. When cinder concrete slabs are used to lighten the dead load of floors and ceilings, it is especially important, because of the increased porosity of the resulting concrete, to have carefully applied bonding materials. Parenthetically, it may be stated here that many builders object to cinder concrete. Other methods of securing smooth ceiling surfaces and at the same time lightening the dead load, such as the placing of hollow tiles or gypsum blocks at the lower surface of ceiling slabs between beams and support members, are recommended. Finishing coats of plaster can then be applied to hollow tile and gypsum block without the use of special bonding materials.

Chemical Paints. Irrespective of the material used for ceiling construction, its surface should be light in color and capable of being refinished by ordinary workmen. Paint is the material which naturally suggests itself for this surface finish, and a smooth plaster surface is one to which the paint can be easily applied. There are a number of good chemical paints on the market; in general, a semi-gloss or egg-shell surface being preferred. Several laboratories have made rather exhaustive tests of chemical paints and enamels, and information may be secured by correspondence which will relieve the individual builder of the necessity of trying out each of these materials for himself. It has been found that the most expensive paints are not necessarily the best, but, of course, it must be recognized that chemical paints are in general more expensive than ordinary factory and interior wall paints. Metal ceilings are not well adapted for

use in a laboratory because of the difficulty of preventing corrosive gases from attacking the metal where it cannot be protected by painting. Tile covered ceiling surfaces are very attractive and offer several obvious advantages, but, owing to high cost and difficulties of attaching to a plain ceiling surface, have had only very limited use in laboratories.

Walls

Requirements. In general, the problem of wall construction is somewhat more complicated than that of ceilings. In addition to the factors of cost and appearance, walls in some places must be sufficiently strong to furnish support for upper portions of the building, and in other places constructed of such materials that they can be easily removed to provide maximum flexibility in the use of the building. Furthermore, in a chemical laboratory it is frequently necessary to provide support for movable apparatus and permanent equipment on the walls of the rooms.

Hollow Tile. Considerable study has been given to the problem of securing a wall of simple construction without the necessity of special finishing. Hollow tile is the material which naturally suggests itself for this use. If a glazed or vitrified hollow building tile of sufficient regularity to make a pleasing and smooth wall could be secured, it would undoubtedly find application in chemical laboratories.[1] Certain inherent difficulties will, of course, always be met with a hollow tile wall, such as the difficulty in attaching apparatus, and the acoustics of a room entirely lined with this material. Painted hollow tile walls have been used in some laboratories, but the general effect obtained is that of an unfinished building. The combination of hollow tile and finish plaster is very commonly used and provides a wall of good heat insulation properties which is relatively low in cost.

Gypsum Block. Partitions of this material are frequently used, as this type of partition furnishes a good foundation for a plaster finish. Due to its softness it is possible to attach small objects to such walls without difficulty. Objections to the use of gypsum block, which might be mentioned, are the slowness

[1] Since this was written, one large laboratory has been finished with a semi-glazed, hollow tile of very pleasing appearance.

with which such a wall dries after construction and insufficient strength to provide support for heavy objects.

Tile Finished Walls. Tile finished walls commend themselves very strongly to the builder who desires to have the best irrespective of cost. The use of tile or glass-faced brick-covered walls in restaurants indicates the attractiveness of such walls, and the laboratories which have been able to secure this type of wall finish are to be congratulated. Tiles used in laboratories are usually about six inches square with white glazed surfaces, but vitrified unglazed tiles offer certain advantages over glazed materials.

Wall Finish. Regarding the finish coat of plaster walls, it can be said that special plasters are now available which are designed to prevent the penetration of chemicals, thus avoiding the necessity of frequent refinishing. In general, however, painting is sooner or later resorted to. As was suggested under the discussion of ceiling surfaces, the paint should be chosen from specially prepared chemical paints. It should be borne in mind that if the wall is to be colored, a problem is presented to the paint manufacturer which has not been studied so frequently as has been the preparation of lead-free, resistant, white paint, and it will be well for the chemist to have a test wall covered with the prepared paint for some time previous to acceptance of the material. It is, however, possible to secure color tints which are free from compounds discolored by sulfur or altered by common chemical vapors and gases. While semi-gloss paints are recommended for ordinary wall surfaces, in corridors and where conditions are unfavorable, a gloss paint or enamel is frequently more serviceable, as it can be cleaned with greater success.

Provisions for Supporting Apparatus on Walls. The problem of providing for apparatus and general equipment on permanent walls, to which reference has been made in connection with wall materials previously discussed, has been met in some laboratories by imbedding vertical or horizontal wooden strips in the masonry of the walls. The chief objections to this practice seem to be that it is difficult to anticipate all places where attachments may be desired, and in time imbedded strips may shrink or decay and later give way.

Brick. This material has been widely used for wall construction and is, in the opinion of the writer, a very satisfactory in-

terior wall material. The kind of brick employed varies from the relatively expensive, carefully shaped, vitrified face-brick to the relatively cheap, porous, soft, cement block. It cannot be denied that the first cost of a face-brick wall is greater than that of a plaster-finished hollow tile or gypsum block wall, but for permanence it is unsurpassed, and the greater expense of maintenance of a plaster wall will sooner or later make the brick wall the cheaper investment. The acoustics of a room enclosed by brick walls is generally good, and it is possible to attach objects permanently to such walls without special difficulty. A wide variety of color effects can be secured by the use of brick, but, in general, light buffs and greys are recommended. Such bricks provide at a minimum cost a wall unaltered by years of ordinary use, and one which can be easily refinished with a wire brush or abrasive stone after an unavoidable explosion or even a small fire. To secure the best results in a laboratory, the bricks should be regular, and joints of mortar as narrow as possible. It is possible to secure a relatively cheap brick that can be laid with the mortar joint no greater in width than one-quarter of an inch. As in the case of exterior brick, it is not desirable to lay the brick in ordinary mortar and afterward apply special pointing mortar to the outer edges. A white or light-colored chemically-resistant cement mortar should be used to bind the brick, and pointing up should be done as the work progresses. If it is not possible to make use of a vitrified face-brick, it is possible to use ordinary brick with considerable satisfaction, particularly as it is found that paint will adhere even better to brick than to ordinary plaster or concrete walls. In addition to the pleasing appearance of a light-colored face-brick, the properties of light reflection from this type of material are generally good. In corridors and offices particularly, a few feet from the floor it is possible to use a darker brick in a variety of pleasing color combinations. Our modern secondary and public school buildings offer many pleasing examples of this type of construction.

Acoustics of Class Room Walls. Brick is recommended for use not only in laboratories but in lecture halls or in class rooms. No one point of construction is more frequently overlooked by architects and chemists than the proper acoustic effects of a class room or lecture hall. By use of special materials, such as cork tile or some of the newer composition wall-coverings and special

plasters, it is possible to avoid this difficulty, but such special treatment is unnecessary if face-brick or ordinary brick are used.

Water-Proofing Walls. Outside walls call for special consideration to prevent the penetration of moisture and provide thermal insulation. Solution of the first difficulty usually solves the second. The necessity for water-proofing should not stop at the grade line. Walls of brick, stone, concrete, or hollow tile, and various combinations of these materials have been found to allow the penetration of objectionable amounts of water when exposed to wind-driven rain. An air space or a continuous impervious membrane of masonry within the wall is the most common preventative, but window construction and presence of ventilation ducts may interfere with this solution. Exterior materials may be impervious to water or may be rendered so by surface treatment referred to earlier in this chapter, and finally, if the amount of water penetrating the walls is not great, furring out the finish plaster will prevent moisture from discoloring interior wall surfaces.

Floors

Concrete. Floor construction is obviously closely connected with that of building and ceiling construction; hence, the material which first suggests itself is concrete. Stone or cinder concrete slabs, finished with varying thicknesses of cement and sand mixture, are very widely used for shop, factory, and office floors, and to a lesser extent for laboratory floors. If a smooth, unmarked surface is laid, cracks are certain to appear. If the floor is marked into regular tile-like designs, it is difficult to keep clean, and unless special hardeners are employed, dusting of the surface takes place. While considerable work has been done on the problem of hardening of concrete, many builders will testify that an entirely satisfactory surface has not yet been produced. After a floor has been laid it can be improved by the application of surface hardeners and with somewhat less success by drying oils, vegetable waxes, and paints; china-wood oil being especially recommended. The general appearance of a floor can be much improved by the addition of various "color mixes." If it is possible to afford it, however, the laboratory builder should give serious consideration to the desirability of applying a surface layer of

another material over a concrete floor, and a wide variety of materials is available for this purpose.

Hard Floors and Comfort of Workers. Ceramic, slate, bitulithic, terrazzo, and cement-composition floors, which may be finished to a smooth surface, are frequently used. Such floors are subject to the common criticism that they are too hard to be comfortable for laboratory workers. This criticism undoubtedly applies with considerable truth in the case of workers who are on their feet in a laboratory for more than two or three hours a day; hence, for industrial, private, and research laboratories, this matter should be given serious consideration. In the average school or college laboratory, however, the shortness of time during which the student is on the floor, and the increased use of resilient shoe soles and heels make this criticism less valid. Some chemists insist that a slightly irregular tile floor is to be preferred to a perfectly smooth concrete or composition floor, the reason being that a slight difference in pressure on the soles of the feet is produced by the irregularities of the tile.

Mastic. At the present time, the materials most commonly used for chemical laboratory floors are "mastics." A number of varieties of this type of floor have been in use for several years in different institutions with apparent satisfaction. In general, mastic floors consist of a chemically-resistant, plastic material, dispersed in volatile hydrocabons and applied in a number of thin coats. Such floors are sufficiently resilient to be comfortable to walk upon, resist the action of ordinary laboratory chemicals with the possible exception of hydrocarbon solvents, can be readily repaired, are water-proof, easily kept clean, and are relatively inexpensive to install. Mastic materials may be applied to the whole floor of a laboratory, or, after the installation of fixed furniture and equipment, they may be applied to the floor surface remaining exposed. The first method has the advantage that it prevents the penetration of water and other liquids into floors and ceilings, and the objection that the installation of fixed furniture subjects the partly dried mastic to severe use. This may seem to suggest the possibility that mastic floors are too readily cut and marred by heavy objects, trucks, and even movable furniture, but, after such floors have hardened for several weeks, pressures of 200 or 300 pounds per square inch have no appreciable effect, provided the object coming into contact with

the floor is reasonably smooth and is not dragged forcibly across the mastic. If possible a mastic floor should be allowed to dry for several weeks before being used. No appreciable settling into a mastic floor is noticed with fixed laboratory furniture built directly on such floors. Mastic composition can be applied to properly prepared old concrete floors, is recommended as a surface treatment for wooden floors, and has been used to refinish wooden-top work tables. Several solid colors are available, the most popular being dark brown and gray-black. Floors of this type should receive an occasional treatment with wax.

Mastic Tile. Mastic composition tile about one-eighth inch thick is also available and can apparently be permanently attached to concrete floors. Under heavy traffic the slight plasticity of the tiles causes the joints to gradually disappear. The smoothness of this and other composition tile floors is dependent upon the smoothness of surface of the underlying concrete. There is a greater possibility of water causing the separation of tile mastic and supporting floor, and this material is more brittle than ordinary mastic. As yet it is little used in chemical laboratories.

Composition Floors. Examples of this type of construction are furnished by "marbleoid" or magnesium oxychloride and wood filler, and the so-called flexible stone tile and sheet floors which have been used to a limited extent in laboratories, and while not as resistant to corrosive chemicals, they offer more resistance to mechanical abrasion than mastic floors.

Rubber Tile. Natural rubber flooring formed with imbedded layers of cotton, vulcanized in tiles and also in sheets of considerable size, is one of the most satisfactory floor coverings for corridors, offices, and school rooms that has been tested by the author. A wide variety of colors is available, the most serviceable being mottled greys. While little use of rubber flooring has been made in chemical laboratories, as its chemical and thermal resistance is sufficiently great to enable it to be used for the tops of chemical work tables, it would seem to be well suited for laboratory floors. The chief objection to the use of a natural rubber flooring is the first cost as this is greater than that of most floor coverings, but where the traffic is sufficiently heavy its superior resistance soon offsets this.

Linoleum. In some laboratories and class rooms, where there is little danger of contact with corrosive chemicals, linoleum is used because of its low cost. It also commends itself because of its resiliency, and the ease with which it can be maintained. It can be permanently attached to concrete or wooden floor surfaces, and may serve acceptably for many years.

Special Floors. Special floor treatment is necessary in certain places. Machine rooms and oil laboratories naturally find mastic, rubber, and smooth composition floors unsatisfactory. Concrete with a surface somewhat roughened, metal gratings, and alundum or carborundum tiles are considered acceptable. Where there is danger of electric shock, perforated rubber mats are generally supplied. Stair treads and the face of ramps may be protected and traction afforded by using material suggested for oil laboratory floors. In rooms where mercury is used, mastic or other material which will not crack should be used, and this material should extend up the walls a short distance, being given a smooth cove finish.

Costs. Some idea of the relative cost of wall, ceiling and floor materials, previously described, may be gained from the following table:

FLOORS

Material for finishing floor of cast concrete or rough masonry	*Cost per sq. ft.*
Smooth, integral hardened concrete—1 in.	$0.15
Mastic	.30
Marbleoid	.40
Linoleum	.45
Terrazzo	.85
Rubber tile, dark colors	.90
Tile, red quarry	.95

WALLS AND CEILINGS

(A) Material for rough wall, 4 in. thick, of various materials	*Cost per sq. ft.*
Gypsum block	$0.37
Hollow tile	.42
Common brick	.47
(B) Material for finishing walls of brick, hollow tile or rough concrete	
Concrete paints—three coats	.06
Chemical resistant paints—three coats	.075
Plaster and chemical paints	.33
Tile—Majolica	1.25
Cost of 4 in. finished wall would be the sum of any one item in (A) and any one item in (B).	
Cost of 4 in. finished wall of face brick at $40.00 per 1,000	.80

Windows

Location. The relation of windows and skylights to natural lighting will be discussed later, but windows structurally are an important part of the outside walls of a building; they determine the architectural effect of the building and the location of partition walls, provide natural ventilation, and influence installation of heating appliances. The size and location of windows are determined by the amount of natural light desired. However, two limitations should be kept in mind in this connection; it is not desirable to have window sills in laboratories lower than the top of work tables, nor window openings nearer than the width of a work table to a partition wall. If ceiling heights are twelve feet or under, window openings should extend to within a short distance of the ceiling.

Types of Sash. Window frames and sash may be classified under three heads; wood, kalameined wood (metal-covered), and metal. Wooden frames and sash have, in the past, been most commonly used, but the number of new laboratories using this type of window is steadily decreasing as builders become convinced that the saving in cost is negligible and the advantages of wooden frames few in number. Some objections to wooden frames are, the relatively large proportion of the available window opening that is occupied by frame stops and cross bars which limits the amount of daylight admitted; such frame stops cannot be made to fit tightly in slides, and swelling and shrinking are marked; weights, cords, and pulleys require attention; it is difficult to admit outside air without causing drafts. It is well to remember, however, that wooden window frames are available in a specially useful variety of combinations of sliding and swinging and double-hinged panels for school room ventilation and lighting.

Metal Sash. This type of sash is in general superior to wood, especially as regards fire resistance and closeness of fit to frames, but it shares certain other disadvantages of wood sash, and is employed chiefly as a substitute for wooden sash where fire resistance properties are desired. Metal window sash of this type is most commonly employed in industry, and in some older laboratories is arranged to open by turning about a central horizontal axis, the upper half of the movable sash extending

inside, and the lower, outside. This type of window offers some obvious advantages over wooden sash windows and commends

Fig. 27. Brown Window.

itself because of its cheapness, but it is more difficult to adjust so as to admit small amounts of fresh air, to apply protective gratings or screens, and the whole of a large window cannot be

opened as conveniently as with the casement types of window. Incidentally it may be mentioned that fly screens are as necessary in a laboratory as in an office building. The ordinary side-hinged casement window is also not so well adapted to laboratory use as the center hung, center-hinged panel type, illustrated in Figure 27. This type of window is easily opened and closed; does not interfere with space immediately inside the sash; can be fastened to allow small amounts of fresh air to be admitted at top and bottom without interfering with gas burners on adjoining work tables; both sides of the glass can be cleaned from within the building; storms and sudden gusts of wind do not injure the sash even if unfastened, the window closes so tightly that there is practically no heat lost by air convection currents, and in common with other metal windows, light is admitted through practically the whole of the window opening.

Interior Finish

Doors. Doors may be of wood, metal-encased wood (kalameined), and steel. In general, the plainer and simpler the door, the more serviceable it is. Smooth surfaces of plain unpaneled frames have the advantage of not collecting dust, and the general appearance is in keeping with the purpose of a laboratory. Glass doors serve to aid in lighting corridors and making it possible, if clear glass is used, to casually inspect a laboratory without entering. Translucent glass panels are used where light is needed but more privacy is desired, as is the case in offices and class rooms. Ventilation can be provided by transoms over doors or by metal louvres in the lower part of the door. Wood is the most commonly used material, but steel and kalameined doors are increasing in popularity. The latter are not appreciably corroded in a well ventilated laboratory, and they serve to reduce the possibility of serious fires.

Design of Trim. As a general principle, the less decorative the finishing trim or wood work, the more serviceable for a laboratory. One of the advantages of monolithic floor coverings is the possibility of carrying the floor material up on the walls as a sanitary base. Where brick is used as interior wall material, special shapes can be used to form door openings. Narrow, steel door frames have a neat appearance and are espe-

cially appropriate with steel or kalameined doors. Narrow moulding, carried around rooms at the height of the top of door frames, furnishes a support that is in a more convenient location for pictures, small apparatus cases, and cabinets than a moulding near the ceiling.

Color of Trim. The color of the interior finish should be in harmony with the furniture and desks, darker colors being more generally used in recently erected laboratories; lessened light reflection is a small factor as walls and ceilings reflect most of the light. Light-colored doors and woodwork are more easily marred by contact with corrosive liquids and gases. The so-called acid wood stains, followed by filler and wax, make an acceptable finish for the hard woods most commonly used. A very resistant and good appearing finish, used by the writer, consists of a coat of asphaltum thinned with turpentine to give the desired color shade, followed by hot paraffin wax driven in with a torch and finally cold-rubbed to a dull gloss. A final coat of ordinary wood wax may be used over the paraffin. Paraffin can also be applied in carbon tetrachloride solution as an original coat, or subsequently as maintenance treatment.

Shelving. Shelving for special purposes will be described in other parts of this book, but it may be worth while emphasizing here the need of making provisions for adequate shelving in offices, class rooms, and laboratories. Frequently this item is not included in furniture and equipment. Shelving, cases, cabinets, and bins of steel can be secured in most places as cheaply as wood, and this type of shelving is entirely satisfactory in a laboratory with the exception of places where corrosive liquids and gases may come into direct contact with the material. Shelving, whether of wood or steel, demands special attention as to protective coatings. Standard black, acid-resistant, wood stain, such as is used on desk tops, is much used on wooden laboratory shelves. Aluminum paint or bronzing, best with varnish vehicles, is another exceedingly effective and permanent surface coating for wood as well as for metal in a laboratory. Duco and similar lacquers are useful on metal or other materials.

Builders' Hardware

Materials. Brass, iron, bronze, and aluminum are some of the materials used for interior and exterior hardware. On ac-

count of the effect of organic liquids and vapors, protection by means of lacquers cannot be depended upon with as much certainty in a laboratory as in ordinary construction. Practically all metal objects in a laboratory, with the exception of those composed of aluminum and zinc, sooner or later become dark or black as a result of the action of hydrogen sulfide. Since irregular dark spots and streaks are very noticeable, an original black finish, applied to builders' hardware and also to cocks and service outlets, may well be considered. Durable black finishes; for example, Bower-barff on iron and imitation Bower-barff on copper alloys are furnished by makers of builders' hardware and plumbers' supplies, and sulfide black coatings can be applied on the job by contractors. In many laboratories, metal parts are installed without surface protection and a natural dark color allowed to develop. This process is more successful on bronze than on brass, and, in general, the former material is recommended for laboratory use in preference to iron or brass. Aluminum and aluminum alloys are finding increased use for metal apparatus and fittings in laboratories, and much can be said in favor of the use of this metal; its color, its low density, and especially its surface resistance are some of the reasons for its popularity.

Locks. Laboratory conditions demand exceptionally good materials and workmanship in builders' hardware, especially locks. Owing to the wide variation in quality and prices, architects and building committees are frequently impressed by the decided saving to be effected by taking the low bid on builders' hardware. It is unfortunate that those who have to experience the annoyance of a non-operative lock do not have more influence in the selection of this and other similar items. The type of lock is important to a laboratory worker. He frequently approaches a locked door encumbered with apparatus and supplies, and a "unit" lock or at least one which can be operated with one hand is a great convenience. "Unit" locks have the additional advantage that the bolt cannot be moved by a knife blade or wire inserted through a crack between door and frame. Ordinary door knobs are very difficult to turn if one's hands are largely used in carrying objects; hence, levers which can be operated with elbow or knee serve a useful purpose. Doors

leading to class rooms, exterior doors, and, in general, doors which do not swing freely or are controlled by pneumatic stops are frequently marred by the use of the feet to assist the hands; metal kick or push plates should be fastened to such doors. The demands of laboratory ventilation make it especially important that doors, transoms, and windows be adequately equipped with stops, hooks, and other devices for regulating their position and the consequent amount of air passing through an opening. Effective devices of this nature aid materially in preventing heat losses and increasing the efficiency of ventilation equipment.

CHAPTER IV

GENERAL VENTILATION AND HEATING

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General Requirements. The interest of the chemist in ventilation is usually confined to the removal of fumes by means of hoods; and the problems of general ventilation, whether of laboratories, class rooms, or offices, have been left to the ventilation engineer. The demands of the chemist for hood ventilation frequently impose a severe burden upon the general ventilation system, and cooperation with the engineer is very necessary. Tables of general ventilation requirements for different types of buildings have been prepared by ventilation engineers. Such tables call for the removal of 30 cu. ft. of air per minute for each student in a school room, each seat in a theater, or each worker in a shop. Somewhat more liberal allowances are usually made for hospitals where as much as 80 cu. ft. per minute per patient are recommended. It is, of course, generally recognized that the temperature, humidity, and rate of movement of air are essential factors in determining the value of ventilation standards based on air volumes.

Laboratory Requirements. If the chemist is familiar with standard ventilation practice, he dismisses it with little consideration, for he observes that a much larger amount of air per occupant than that indicated by the figures above is withdrawn through hoods. In doing this he neglects the important fact that if the inlet is not properly located, air drawn through a hood may not be as effective in general ventilation as air from other locations in the room. The writer has visited laboratories where 300 cu. ft. per minute were being removed for each student, and yet all of the room above the desk level was filled with an

objectionable haze of ammonium salts. Removing an additional 50 cu. ft. of air per minute per student from the top of this laboratory effected a practically complete removal of all noticeable fumes. This emphasizes the fact that during processes of evaporation and chemical action contaminated air may escape hood openings and remain more or less undisturbed in the middle and upper part of a laboratory. If, however, air is admitted at the upper part of a room these difficulties are not met. In general, warm air should be admitted at the top and withdrawn from the bottom of the same side of a room. Or if the incoming air is not pre-heated, it should be admitted at the bottom of the room and withdrawn at the top. It is not only difficult but unnecessary to attempt to confine all of the slightly objectionable chemical fumes to hoods. It is frequently better—for example, in an organic laboratory—to consider the room as a whole more or less as a hood, as this makes it possible to provide a better atmosphere for work with an expenditure of less energy in moving and heating air. The foregoing statements are not advanced with the idea of depreciating the importance of chemical hood ventilation, but merely to draw attention to the fact that additional ventilation is frequently desirable. It is well to point out at the outset that while the need of ventilation equipment other than for hoods is frequently overlooked by the chemist, yet the ventilation engineer sometimes recommends excessively large and expensive installations for general ventilation of chemical laboratories, apparently neglecting both natural and hood ventilation in his estimates. The maintenance and operating cost of such equipment frequently becomes excessive. On the other hand, those responsible for the erection of a chemical building should recognize that the ventilation of a laboratory is not so simple as that of office and school buildings, and relatively large sums of money must be set aside for this purpose.

Fundamental Principles of Ventilation. There is nothing mysterious about ventilation engineering. Two very simple fundamental principles, carefully kept in mind, will enable the chemist to understand most of the problems with which he is confronted. These are—first, that warm air rises; and, second, that the viscosity of air is slight. As an example of failure to observe the first principle, the writer can cite a condition re-

cently observed in the ventilation of a lecture room by admitting air at the bottom of the room and withdrawing it diagonally opposite at the upper part of the room. Owing to the fact that the temperature of air on the floor of the lecture room was a few degrees below the temperature of the admitted air, due to the effect of outside windows, the warm, fresh air rose immediately to the ceiling and passed along this to the point where it was withdrawn, leaving the major portion of the room in which the seats were placed unventilated. Lowering the temperature of the incoming air or admitting air through well distributed openings beneath the seats completely removed the objectionable odors which had previously accumulated in the lower part of the room, and did this without increasing the total amount of air withdrawn from the room. Equally satisfactory results could have been secured by admitting warm air at the upper part of the room and withdrawing at the lower.

Natural Ventilation. Recent tendencies in general ventilation are towards making increased use of natural ventilation.[1] This applies especially to window ventilation in school rooms, but it may be applied also to stacks and vertical ducts in the interior of buildings. The chief difficulties involved in the utilization of natural ventilation in a laboratory are interference with hood ventilation, which is necessarily forced, the necessity of warming incoming air during a major portion of the year in most climates, and the effect of direct drafts upon gas heating appliances. In general, it is seldom desirable to use natural window ventilation in laboratory rooms. If decreased pressure is maintained throughout the building and the admission of limited amounts of relatively cold air will not interfere with the convection currents and air drifts, normally anticipated by the ventilation engineers, this may be considered. In offices and some other small rooms, it is possible and frequently desirable to depend upon window ventilation with appropriate window deflectors. Special methods of supporting and opening ordinary wooden sash windows and appropriate construction of steel sash windows, such as were described in Chapter III, contribute to the success of this most simple method of ventilation.

Requirements per Student. Regarding the quantity of air to be withdrawn from different laboratory rooms, it is difficult

[1] Report of New York Commission on Ventilation. E. P. Dutton, 1923.

to set up definite standards because of the wide variation in efficiency of air movement through such rooms. Ceiling heights obviously influence the amount of air that must be withdrawn in a lecture room or class room, especially if it is not used continuously. In general, however, the standard ventilation allowances are insufficient. In lecture rooms and class rooms, a volume of 100 cu. ft. per minute per occupant is frequently exceeded; in some laboratories as much as 200 cu. ft. of air per minute is withdrawn. It is certain that the builders of a chemical laboratory will never violate state or municipal laws regarding the minimum amount of air to be withdrawn from assembly halls if they follow the practice of modern laboratory construction.

Types of Fans. Air employed in ordinary ventilation is generally moved by means of electrically driven fans. In general, these fans are the low-speed type having a large number of blades or vanes on the fan wheel. This type of fan is not only cheaper to operate and maintain, but handling relatively low velocities of air is quieter in operation, a point which it is very important for the builder to keep in mind. If possible, a ventilating fan should be removed some distance from the room it is desired to ventilate, especially if this room is a class room or office, for fan noises are readily transmitted through short air ducts. It is frequently desirable to have a reduction of motor speed by means of belts or chains in order to secure the necessary low speed. Leather or composition belts have been used, but silent chains are preferred by those who have given the matter careful study. Direct drive from the motor shaft is possible with fans relatively small in diameter, as speeds down to approximately 400 revolutions per minute are feasible with standard motors. It is, of course, possible to secure an electric motor which will operate at speeds of less than 100 revolutions per minute, but the size and weight of the motor as well as its cost make such an installation inadvisable. Special precautions should be taken to prevent the transmission of vibration from fans to the structural framework of a building. Layers of cork or combinations of cork and wooden bases are usually satisfactory if the fans are properly constructed.

Fan and Duct Materials. The materials to be used for ducts and fans for general ventilation should receive more attention

in a chemical laboratory than is given in general building construction, for although general ventilation is not designed to handle corrosive gases, varying concentrations of such substances are likely to get into the so-called clean air systems. Vitrified tile wall ducts are recommended, but if sheet metal ducts are used it is desirable to protect them on the inside by corrosion-resistant coatings. The fan housing and wheel should also be protected, but it is not generally necessary to employ special alloys or inactive metals.

Fresh Air Supply. It is obvious that the fresh air supply of a chemical laboratory should be given careful consideration. While no definite quantities of air can be listed as needed for each worker in a laboratory, the study of a number of modern chemical buildings indicates that it is necessary to supply from 100 to 300 cu. ft. per minute for each laboratory working space and lecture room seat in the building. The demand is not usually so great as the total number of seats plus the number of laboratory working spaces, as both types of rooms are not often utilized at the same time, but it certainly is in accord with modern practice to provide for the warming from 0° to 60° F. of 250 cu. ft. per minute for each laboratory working space, or 200 cu. ft. per minute for each lecture room and class room seat. The amount of heat to be supplied to the building in this way is, of course, to be supplemented by direct radiation sufficient to offset the usual loss from outside walls, windows, and doors. Calculation of the number of heat units required for direct radiation in a building can safely be left to the ventilation engineer. Since the usual methods of calculation do not take into consideration the very appreciable amount of heat supplied in a laboratory by the heating appliances employed, a comfortable and frequently useful surplus of heat is generally provided by the engineer.

Type of Heating System. Heat is usually supplied to laboratories by means of steam; the pressures may be relatively low but should be constant and sufficient to effect uniform distribution. Steam under pressure of a few pounds is well fitted to meet the sudden demands thrown upon the heating system, especially on intake heaters, occasioned by turning on a number of exhaust fans when work is begun in various laboratories. For general heating or direct radiation in rooms, hot water

offers some advantages; namely, uniformity of temperature, greater life of equipment, and more efficient conveyance of heat from a distant central power plant, but, as indicated above, hot water is not sufficiently responsive to be used in intake heaters and stacks, and is more likely to freeze when full circulation is not maintained.

Location of Radiators. The most common location for direct radiation is under windows and this is generally satisfactory, but the nature of the operation to be carried out in the room and the position of workers should also be considered. It is objectionable to work close to a steam radiator, and shields or inclosed radiators may be necessary in some places. Hot water radiators are less objectionable on this score because of the lower temperatures employed. The shape of radiators, the materials employed in radiators and connecting piping, and the type of return system are matters largely determined by the position in the room, the nature of the system, and standard heating practice. Recent innovations in the location of heating pipes, such as imbedding them in concrete floors and walls, offer interesting possibilities for work rooms in chemical laboratories.

Relation of Incoming to Outgoing Air. There is considerable variation in the combination systems of forced ventilation employed in laboratories, but in general the capacity of the exhaust fans for hoods and general ventilation should exceed the capacity of intake fans or gravity heating stacks. The proper balance between these two factors must be carefully worked out if each part of the building is to be properly ventilated. In general, the highest velocities and the strongest suction should be maintained on the hoods; next on the general exhaust ventilation; and the least pressure on the incoming air. It is possible to work out a number of different schemes combining push-and-pull fans, with or without natural gravity ventilation in outgoing stacks or incoming ducts, the details of which it is unnecessary to outline here. The most common practice in modern installations seems to be to combine push-and-pull fans through appropriate distribution ducts, so that the amount of air forced in is from 10 to 30% less than that withdrawn by the exhaust fans in any one enclosed portion of the building. More specifically, the amount of air withdrawn from laboratory rooms is

somewhat greater than that supplied, and the amount withdrawn from offices and class rooms somewhat less than that supplied. In this way fumes from laboratories do not find their way into offices and places where there is little source of air contamination. In some small laboratories, movement of air is produced entirely by forcing fresh, warm air into various rooms and allowing it to find its way out through simple tile ducts leading from hoods and registers in offices and class rooms. With this system of ventilation as well as in a balanced push-and-pull system it is, of course, essential to have windows closed at all times.

Air Conditioning. It is frequently desirable to purify air admitted to a laboratory, especially if the building is located in a congested neighborhood or where the outside air is frequently contaminated. For a number of laboratory operations, it is also desirable to regulate the humidity. Several well-tried systems for air conditioning are in use; the principles employed being washing the incoming air with small streams of water or passing it through light-weight canvas or muslin bag filters. Such systems are highly desirable in laboratories where accurate work is to be carried on.

Temperature Control. It is, of course, to be expected that no modern laboratory will be without thermostatic control of the temperature within the building and the temperature of the incoming air. Thermostats should be located at points experiencing average temperature changes. In order to control the temperature of incoming air it is usually necessary to have multiple thermostats and a series of heating coils. The amount of heat supplied in one set of heating coils is dependent on outside temperatures, another on the temperature in the air inlet system beyond the heating coils, and the third on the temperature of the rooms being supplied with fresh air.

Plenum Systems. In order to effect a distribution of incoming air to various parts of the building, plenum spaces, underlying part or all of the building, are sometimes utilized in place of intake fans or gravity heating stacks with connecting ducts. This system makes it possible to eliminate a large number of ducts for incoming air, and is very commonly used in school building construction. If a forced exhaust ventilating system, which varies from time to time in various parts of the building,

is used, the plenum space acts as a convenient reservoir of partially warmed air. It is necessary, however, to insure steady and adequate outward movement of the air from special plenum spaces if back-drafts and mixing of air currents from different rooms are to be avoided.

Window Inlet Air Heaters. As a substitute for large plenum spaces or extensive duct systems, some use has been made of simple inlet air heater and fan outfits placed below windows. These devices consist of enclosed radiators and small fans, driven by quiet motors, the outfit being of such dimensions that it can be placed in a window recess since it occupies only slightly more space than an ordinary radiator. Fresh outdoor air can be forced into the room or the air in the room recirculated over the radiator at will. While most of the installations of this type have been in school rooms, it is feasible to make use of them in laboratories, especially as a means of supplementing large, inlet-air heating systems.

Air Cooling. Artificial cooling of incoming air for general laboratory ventilation has been observed by the writer only as an incidental but nevertheless valuable result of the employment of air conditioning systems. Special refrigeration rooms are, however, quite common in laboratories where extensive biochemical work is carried on; small ammonia systems are generally used to cool the brine circulated through such rooms. In the future, however, we may confidently expect that some enterprising laboratory designer in a locality where summer temperatures are uncomfortably high will introduce the refrigeration of incoming air as an example of efficiency engineering applied to chemical work in industry or in school.

CHAPTER V

HOOD VENTILATION

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This chapter deals with the confining and removal of chemical fumes, corrosive and poisonous gases and vapors, and also water vapor and vapors of other volatile liquids, not necessarily corrosive nor poisonous, but objectionable in high concentration. This type of ventilation is largely effected through hoods or, as they were formerly called, fume closets, connected to fans or other means of producing positive draft.

Types of Hoods. Hoods have been seriously recommended by chemists, varying in size and capacity from an ordinary four in. glass funnel, attached to a water aspirator, to structures 100 or more sq. ft. in area. Various classifications of hoods, which merge more or less into each other, have been suggested, such as individual and general or side-wall hoods, open and closed, up and down draft, natural and forced draft, etc. In the minds of most chemists, however, there is a definite distinction between an individual desk hood, used by one or two students and located at the usual work table, and a side-wall hood within which considerable apparatus can be assembled and in the use of which several workers may cooperate.

Individual vs. General Hoods. Advantages claimed for the small hood on the table are: first, economy of space (such hoods being located over the usual working space); second, economy of movement (the worker is not required to walk far to secure the benefit of hood ventilation, and as a result it is claimed hoods are more frequently used); third, small, relatively inexpensive hood structures. Advantages claimed for the larger side-wall type of hood are: first, the apparatus involved in an experiment

is completely enclosed; second, because of dilution and temperature equalization, a more complete removal of fumes is effected for a given volume of air exhausted; third, greater simplicity of duct and connecting systems; and fourth, multiplicity of small desk hood structures may make the side-wall hood system less expensive. It may be possible to effect a complete removal of chemical fumes by means of individual hoods; in general, however, it is the opinion of this Committee that this has rarely been done. If the apparatus used by the worker is compact and the quantity of objectionable fumes is small, it is possible to make use of a small hood; the smaller the hood, however, the greater the need for completely enclosing the apparatus or the source of corrosive and poisonous gas. If the objectionable material is gas or vapor and it is produced without the use of heat, its removal is relatively easy, but if the use of an ordinary Bunsen burner is necessary, air movements of considerable volume and velocity are set up. Outward horizontal velocities as great as 250 ft. per minute can be produced in the upper part of the opening of a small individual type hood by the heat from one Bunsen burner. In a larger hood with considerable enclosed space above the level of the opening, these rapidly moving air currents are caught and the movement is restricted. It is thus evident that unless the apparatus being heated is carefully placed with reference to outlets, an open, small individual type hood has small chance of completely removing fumes generated in an experiment. It is difficult and in some cases impossible to completely enclose the apparatus used in student experimentation in a small hood, and the velocity of air through such openings as are necessary for control and observation must, naturally, be very great.

Individual Hoods. Recent types of individual hoods are shown in accompanying Figures 28 and 29. In this and other similar types of hoods, air is withdrawn through horizontal openings at the back of the hood, top and bottom, and a rolling curtain of incoming air, produced by the curvature of the front edge of the hood, restricts the outward movement of objectionable fumes. From 200 to 350 cu. ft. per minute are withdrawn from individual hoods of these types. While the writer has had only limited opportunity to observe such hoods in actual operation, it is reported that they are functioning more satisfactorily for

elementary and qualitative analysis classes than the average individual hood. For more advanced work, this type of hood does not serve so well, and for general industry and research it is out

Fig. 28. Chemical Hood, Columbia University.

of the question. If an individual hood is made sufficiently large to accommodate the apparatus required for the conduct of ordinary quantitative and qualitative analysis, that is, to allow free

use of burners and steam baths, and there is space and proper bottom draft to remove excess hydrogen sulfide used in precipitation, the structure will become so large that it will inter-

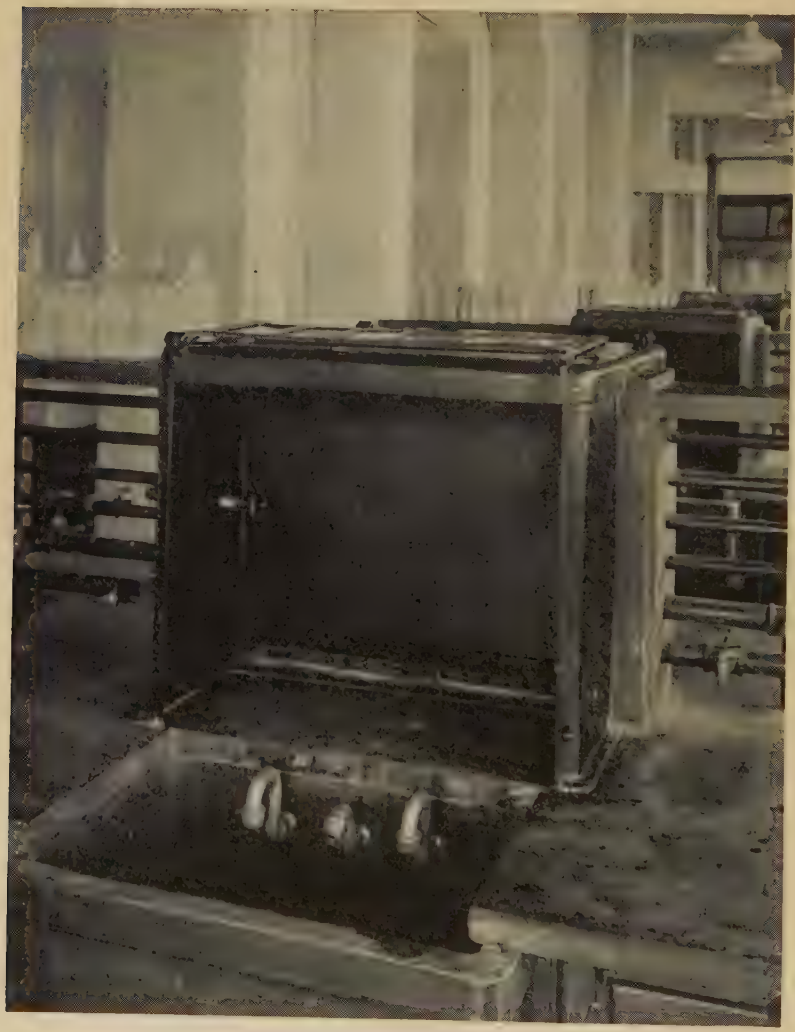

Fig. 29. Individual Hood, Harvard University.

fere with the lighting of the room if placed over each desk. If only a few working spaces are combined in one connected section of desks—and this arrangement has several advantages which

commend it—and one end of the hood is placed against the wall, it is possible to use a hood for certain relatively elementary types

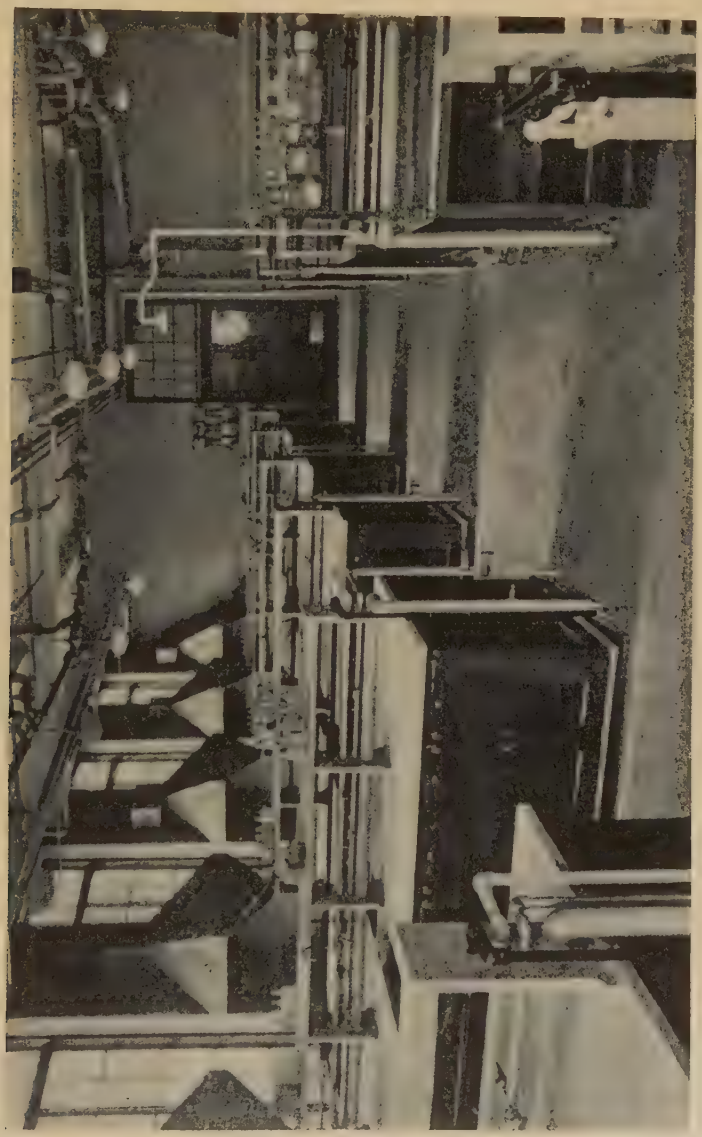

Fig. 30. Hoods at End of Desks, Wesleyan University.

of work, which is a combination of the individual and the side-wall type, such as is shown in the accompanying Figure 30. With

this type it is possible to have a hood near the worker, occupying in fact part of his regular working space, which causes no interference with natural or artificial lighting. Since the space under the working surface of the hood can be utilized for apparatus lockers, either more working space will be available, or more workers can be accommodated in proportion to the floor space than with the conventional side-wall hood.

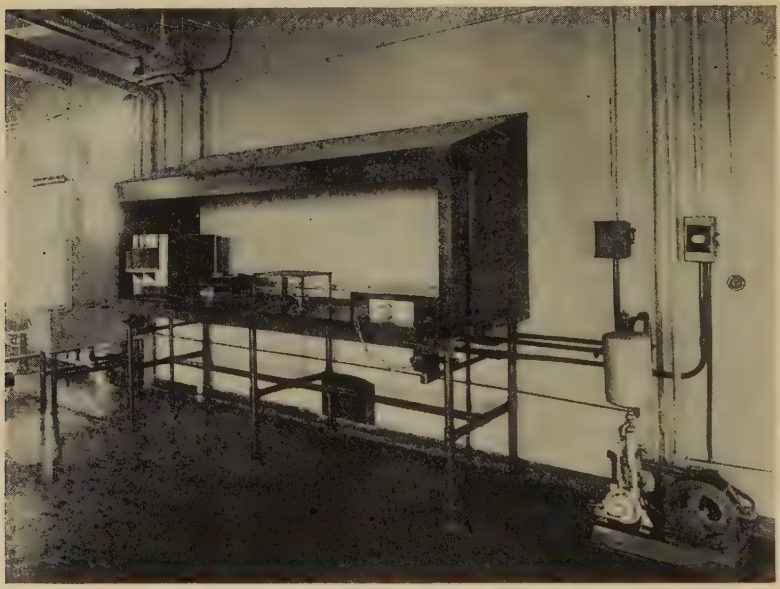

Fig. 31. Cornell Open Hood Type.

Open or Closed Hoods. The earliest hoods were apparently open fireplaces and later cupboards and closets in which apparatus evolving objectionable fumes could be placed until the reaction was completed. Movement of air through the enclosed space was effected by connecting it to a chimney or to the outside air. This method of disposing of objectionable gases; that is, liberating them in an enclosed space more or less ventilated, has persisted down to the present day. It cannot be denied that fumes can be removed with the greatest economy of ventilation by placing them in a space which is entirely separate from the one in which the worker is located. There are but few substances which are so dangerous as to call for such complete

removal from the neighborhood of the worker; moreover the primary object of a hood is to enable the worker to carry on with ease and comfort a given reaction while at the same time observing and controlling its progress. With nine-tenths of the reactions carried out in a chemical laboratory, evolving objectionable fumes, this can undoubtedly be best done in an open hood.

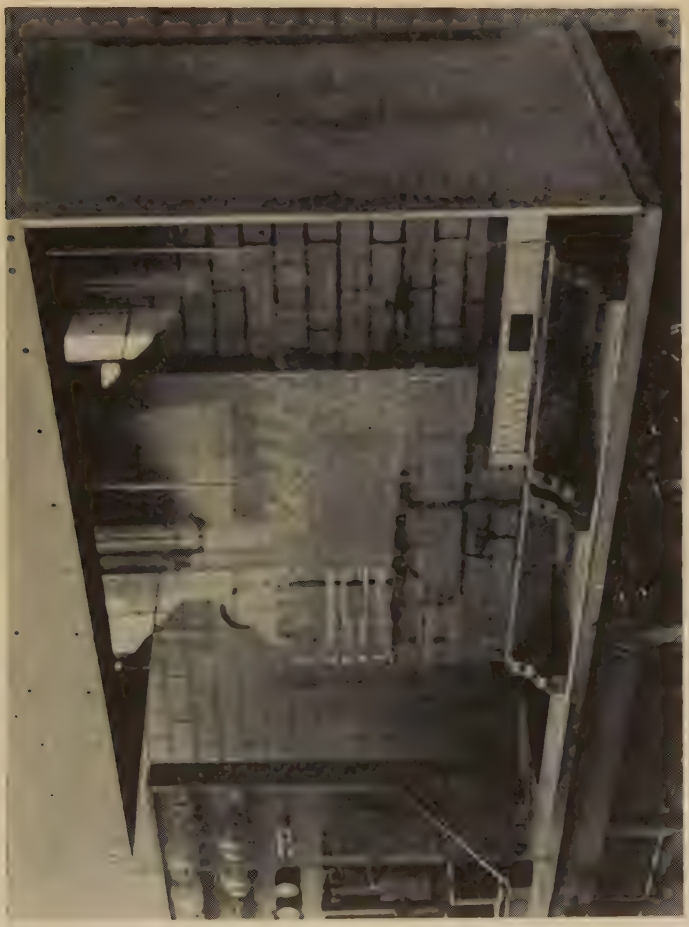

Fig. 32. Hood Screens, Wesleyan University.

As has already been stated, it is almost impossible to carry out chemical operations without having a portion of the hood open. There is always more or less leakage around hood windows. A certain minimum volume of air must, therefore, be drawn into

the hood at all times, and the expense and difficulty of maintaining windows, sliding panels, or other hood-closing devices in a corrosive atmosphere is so great that it is generally simpler and cheaper to remove a somewhat larger body of air from the hood, do away with all closing devices or windows, and thus enable the worker to have ready access to the apparatus that is being used in the hood. This general conclusion seems in accord with the practice of the best modern laboratories, as it can be observed that an increased use of open hoods is being made. Improved design of hoods and proper location of exhaust openings contribute, of course, to the increased use of open hoods, a good example of which is shown in Figure 31. While with properly designed hoods it is the experience of several laboratories that such devices are unnecessary for the small number of reactions evolving substances very dangerous even in small concentrations, some chemists may wish to have available special removable screens or shutters of glass or other non-combustible material. Such a device, shown in Figure 32, is composed of wire glass screens supported on small wooden feet. It has the additional use of protecting the worker from injury by explosion.

Materials of Hood Construction

Glass and Wood. A considerable variety of materials is used in the construction of hoods. Formerly they were almost always constructed of combinations of wood and ordinary glass, but breakage of the latter and the fire risk involved in the use of the former have combined to bring about a decrease in the use of these materials. The substitution of wire-glass for ordinary glass is a decided improvement, and this material is being satisfactorily used for the sides and tops of hoods where the natural or artificial lighting, effected through the opening of the hood, is insufficient.

Soapstone. Soapstone has been very successfully used in the construction of all parts of hoods and even of ventilation ducts. A highly satisfactory hood of pleasing appearance is the result. Some of the objections to the use of soapstone are its expense and the weight of the hoods whose proper installation calls for strong floors and heavy pipe supports. It is manufactured with difficulty and is subject to considerable breakage. Examples are shown in Figure 28, and also Figures 31 and 35.

Asbestos Wood. Asbestos wood is extensively employed in the construction of laboratory hoods. The hoods shown in Figure 30 are constructed of this material. The chief objections to the use of asbestos wood are that it is somewhat more readily attacked by concentrated condensed acid vapors than soapstone, and it has been difficult to join separate sections or slabs. This operation has usually been performed by using an angle iron, which is, of course, objectionable on the inside of hoods. The hood shown in Figure 30 however, has been formed without the use of metal on the inside of the hood or ducts, by a method recently devised by one of the large manufacturers of this type of material. There has recently become available a cement which is used in joining sections with an almost invisible joint.

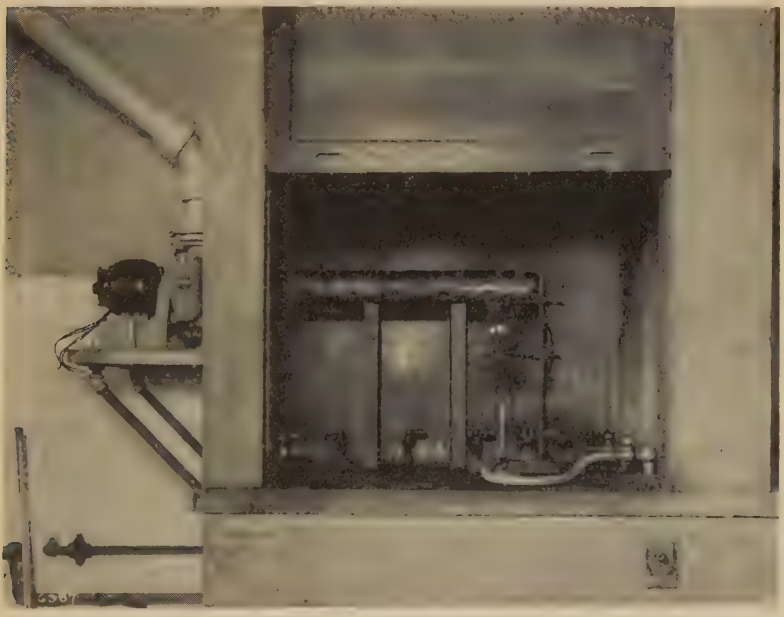

Fig. 33. Kjeldahl Tube Wall Hood.

Miscellaneous Materials. Various protective metals and combinations of metal and glass have been employed in hoods, especially in those of small individual types. A combination of glass, mica, and aluminum alloy is utilized in the one shown in Figure 29. If a hood is used continuously for evaporations or digestions, liquids are likely to condense on horizontal portions

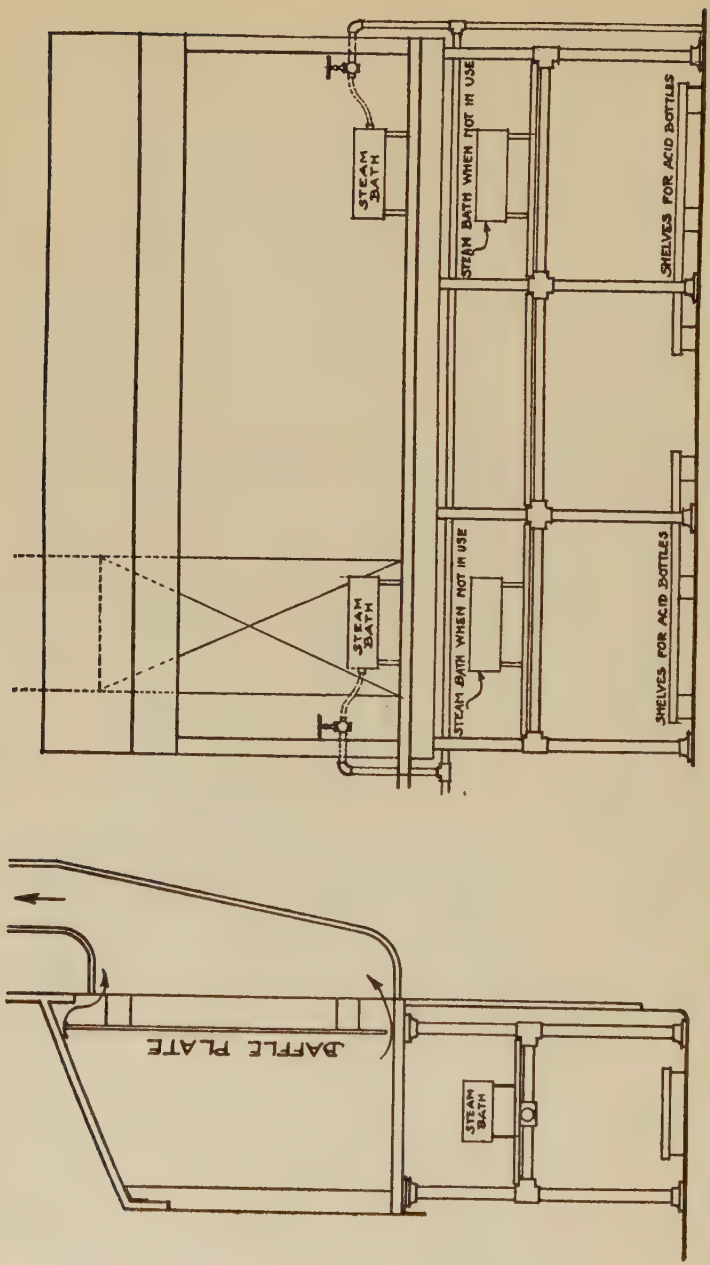

Fig. 34. Diagram and Section of Wall Hood, Cornell University.

inside the upper part of the hood. To prevent this condensed material from dropping upon the apparatus in use in the lower part of the hood, it is necessary to construct the upper part of the hood so that any horizontal surfaces slope slightly and thus drain to the front or preferably to the back of the hood.

Exhaust Openings. The hood frame structure or body, which has been the subject of our discussion up to this point, is after all only a means of providing direction and regulation of the air currents by which objectionable substances are removed. The size and position of air outlets from the hood constitute a very important problem connected with hood construction. The variation in density and temperature of gases and vapors, which it is necessary to remove from a chemical laboratory, or more particularly from the interior of the hood, makes it evident that if a hood has an opening in only one position, all substances cannot be successfully removed. The group of substances which are lighter in density than air, under the conditions in which they are liberated inside of a hood, is larger than the list of those heavier than air under the same condition. Consequently, a larger volume of air should, in general, be removed from the upper part of the hood. A ratio that has been found to be satisfactory in some laboratories is two volumes from the upper part of the hood to one volume from the lower. It is not only necessary to remove air from both the bottom and top of the hood, but also to remove it through openings that extend for as great a distance along the back of the hood as does the opening of the hood across the front. That is, the outlet from the hood should be so placed as to produce a gradual drift of air across the whole of the open front of the hood, with maximum velocities at the upper edge of the opening and next greater at the bottom of the opening. If possible, this drift should be so controlled that around the edges of the open front of the hood, the velocity is sufficiently great to form what may be described as an air canopy, which will draw into the hood the gases liberated near the front, or gases which, because of air currents outside of the hood, are likely to escape. Some hood designers think that it is desirable to withdraw air through openings located around the entire periphery of the hood opening, and this in addition to openings extending at the top and bottom of the hood entirely across the back of the structure. For a large hood, the addition of these

openings along the front edges calls for a somewhat complicated system of small ducts; moreover, if the hood is properly designed it will operate satisfactorily with openings only along the back. Another successful and much-used method of withdrawing air from a hood is effected by means of a baffle-plate, usually of asbestos wood, placed across the back of the hood two or three inches from the rear wall against which the hood is placed, with openings along the top and bottom. The opening which leads to the duct connecting to the exhaust fan is placed in the wall behind the baffle-plate, and if the size and shape of this opening into the flue and the size and shape of the openings around the baffle-plate are properly proportioned, the hood will draw evenly.

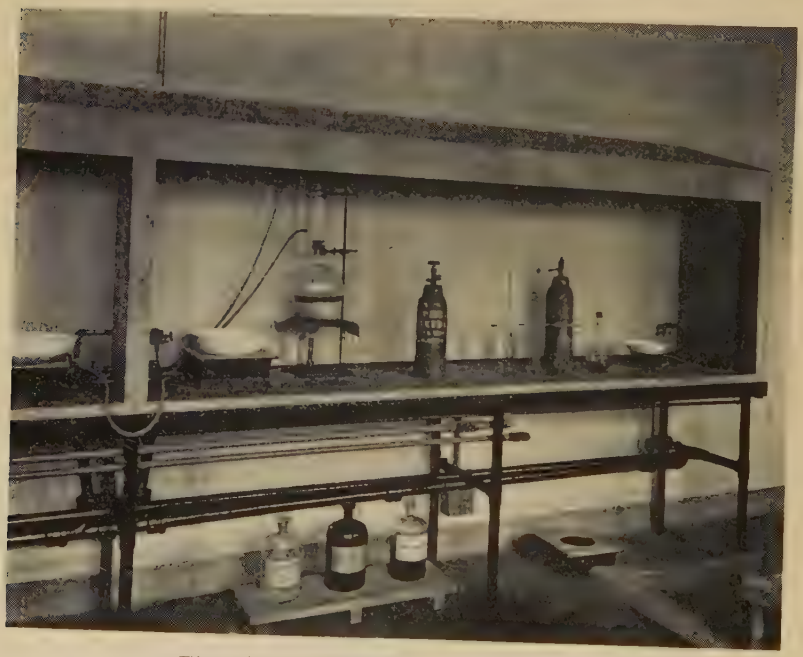

Fig. 35. Open Hood, Cornell University.

Such a hood is illustrated by Figure 35. If the walls of the room in which the hoods are placed are of plaster or ordinary composition materials, the baffle-plate serves an additional function of providing a refractory interior lining of the hood. The wall against which baffles are placed need not be plastered. If the building wall in the hood is of refractory material, such as

vitrified brick or tile, a slight saving in cost and a gain in depth of the hood can be secured by constructing small vertical ducts of refractory material which extend down from a horizontal collecting duct at the top of the hood or from the wall opening leading to the fan, to a small horizontal duct which provides the necessary openings along the bottom of the hood.

Design of Hood Canopy. In any type of general hood, the upper part of the structure acts as a reservoir for the collection of gases lighter than air, which, by dilution and cooling, are brought more nearly to the density of air, and thus, mixing more readily with it, are withdrawn with greater ease. It is desirable to have the top of the hood slope up toward the rear, forming an angle of from 45 degrees to 60 degrees with the vertical wall. The addition of a small apron or narrow vertical panel along the front of the hood is essential to the proper operation of an open hood.

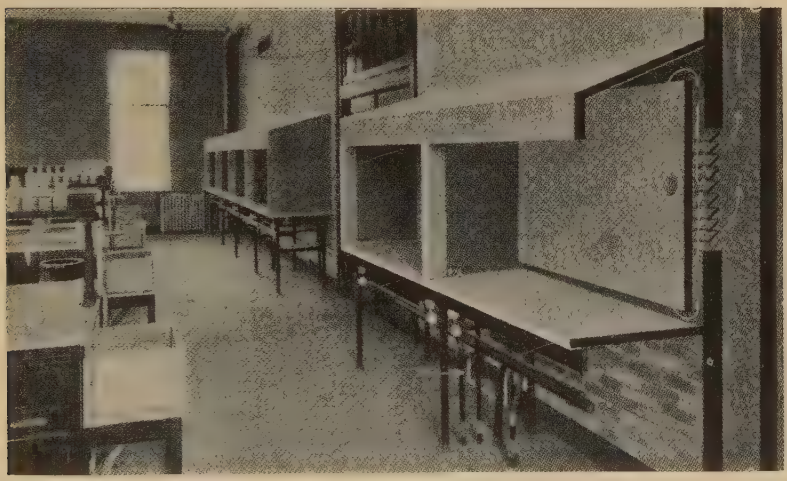

Fig. 36. Section of Open Hood, University of Richmond.

Duct Openings—Size and Air Velocities In. As has been mentioned, the uniformity with which air is withdrawn from the opening at the front of the hood is regulated in the first place by the size of the openings and by the shape of the hood, and also by the position of the outlet which leads to the exhaust fan, and its relation to the slits or baffle openings from the hood interior. If the last mentioned openings are symmetrically placed with

respect to the opening in the back of the hood, it is possible to effect regular distribution of the air in the hood by means of openings that are approximately the same width at all places, but if the duct leading to the exhaust fan is in a position unsymmetrical with reference to the back of the hood, it may be necessary to make adjustments in the size of the openings into the hood. Owing to the slight viscosity of air, it is very difficult to effect this uniform distribution unless the openings are very carefully proportioned. Since air velocities are varied by very slight inaccuracies in construction, it is desirable to have some means of altering the size of the opening after the hood is completed and ready to operate. Uniform distribution in the withdrawal of air from the hood can be effected more readily if a high velocity is maintained through the duct openings. In some experiments, carried on by the writer, it was found necessary to raise the velocity of air in a duct opening to approximately 2,000 ft. per minute in order to effect uniform distribution. From this one might conclude that it would seem natural to recommend the use of high velocity air systems in all hoods. However, a number of other factors must be discussed before one can make final decision in this matter.

Air Velocities in Ducts. In general it is more expensive to move air at high velocities than at low, but for equal volumes of air, smaller ducts, fan housings, and openings to the outside air are necessary. It is cheaper to construct small ducts, and, as the cost of the material of which the duct is constructed increases, this saving becomes greater. Consequently, if it is desirable to construct a duct system entirely of chemical resisting materials and to provide a fan-housing and fan of refractory materials or of materials which can be surface treated to prevent chemical action, it may be cheaper to use high velocity air. Another factor which has to be considered is the size of the duct in the wall. If the ducts are to be carried in outside walls, and the building is of more than two stories, wall thicknesses become excessively great on account of the large ducts necessary for low velocity air. If the ducts are carried on or between inside walls, this objection is less valid and has weight only as the interior area of floor space is decreased by ducts. Concerning the relative merits of ducts in outer or inner walls, the general practice favors the latter location. Differences in draft are not

appreciable, and convenience of location should be the deciding factor. Another fact which must be kept in mind is the greater likelihood of fan noises or air pulsations being set up by the wheels of the fan used in high velocity equipment, which, however, may be eliminated by careful ventilation engineering. With as many factors involved as have been indicated in this discussion, it is impossible to make general recommendations regarding the relative merits of these two systems of exhausting chemical fumes. In most installations, however, the writer recommends high velocities of air where the concentration of corrosive and poisonous materials is relatively great, and low velocities where the concentration is relatively small.

Air Velocities in Hood and Volume Removed per Worker. Whatever the method of moving the air from the hood structure, there is general agreement upon the velocities which should be maintained through the openings in the front of the hood. If the hood structure is properly designed, with continuous inlet slots at top and bottom of back of hood, and strong air currents from without the hood be avoided, it is possible to prevent the escape of objectionable vapors and gases from the open type of hood, ten ft. or less in length, by a velocity of from 35 to 50 linear ft. per minute across the entire hood opening. Under certain conditions, somewhat wider variations in the velocity may be employed. For laboratories in which the least objectionable type of work is carried on, a velocity of from 25 to 30 feet per minute across the opening is sufficient, and the maximum that is required for the handling of very dangerous vapors is usually considered to be from 50 to 60 ft. per minute. The total amount of air that is withdrawn from the hood for each worker consequently depends upon the size of the opening in the hood, and this, of course, will be true whether open or partly closed hoods are used. In general the height of the opening of the hood above the floor is sufficient to enable the worker to lean into the hood without having his head come into contact with the upper structure. Heights of from five ft. ten in. to six ft. two in. above the floor have been used in modern laboratories. If the top of the working surface is 36 to 39 in. above the floor, it is seen that the vertical height of the opening of the open type hood will be three ft. If two ft. are allowed for the length of the space occupied by one worker, it is evident that the opening he makes

use of will be approximately six sq. ft. in area. For a velocity of approximately 35 ft. across the opening, a little over 200 ft. per minute will be removed for each worker. From the different velocities across the hood opening mentioned above, it is evident that the total amount removed for each worker will vary from 150 to 350 cu. ft. per minute, depending upon the type of work in which he is engaged. Comparing these volumes with those employed in recent individual desk hoods, it is evident that it is almost equally expensive to ventilate the smaller, individual hood.

Location of Hoods. The most common location for large hoods is along the inner wall of a laboratory. Placing hoods in one connected group simplifies ducts, but has the disadvantage of causing congestion when all hoods are in use, and also of making it necessary for a large proportion of workers to be some distance from their ordinary work tables. Another common arrangement is the separation of two laboratories by a row of hoods placed back to back. Hoods arranged in this way should have some sort of center partition, as cross air currents tend to blow fumes from under such hoods. A somewhat better arrangement, as far as accessibility and the avoidance of congestion is concerned, places all hoods on both side walls at the ends of aisles between desks. This location may place hoods between windows, but there is no objection to this arrangement, either because of interference with natural lighting or because of air currents from windows. However, as has been mentioned previously, in the operation of open hoods or, for that matter, any type of hood, air currents from open windows or doors should be avoided. The location of individual hoods depends so largely upon the size and type that it is impossible to make definite suggestions. In general, the end of the working space opposite the sink and toward the back of the table seems to be favored, although one hood shown in Figure 29 is placed behind the sink with the idea of removing fumes liberated when apparatus containing objectionable materials is washed. If somewhat larger, semi-individual hoods are used, they may be placed back to back in the center of the working space used by four persons, but this position is likely to interfere with natural lighting unless ceilings are unusually high. Placing this type of hood on the wall end of a desk avoids

light interference, and has the additional advantage that workers walk back and forth less in front of the hood and thus interfere less with its operation.

Duct Materials and Dimensions. The materials used in the construction of ducts for the confining of air used in chemical ventilation vary with the nature of the systems installed, as has already been indicated. With low velocity air, vertical ducts in walls are commonly constructed of tile, such as is used in the lining of chimneys, or round vitrified tile without hubs. The latter is somewhat more resistant chemically and correspondingly greater in cost when installed. For horizontal ducts, particularly those in attics and in spaces adjacent to fans, sheet metal may be used, but the builder using this material must certainly contemplate the replacement of these ducts in a relatively short time. Horizontal ducts are sometimes constructed of protected metals, and if the protection is properly applied or the protective material is sufficiently resistant, these ducts will be found to serve successfully for a number of years. One of the most convenient materials to use for horizontal ducts is ordinary sewer tile, and this material, when laid with the proper kind of cement joint, can be made chemically resistant, thereby constituting a permanent installation. Rectangular, asbestos-wood ducts have been used in a number of laboratories, and this material is sufficiently resistant to provide what may be called a permanent installation. Care should be taken to seal all joints and make them air-tight, as otherwise there will be a loss of draft. In any type of duct or fan housing, it is desirable to make provision for the removal of condensed vapors. Furthermore, if a ventilation duct exhausts vertically into the open air, water from rain or snow will be added to the condensed material. If relatively high air velocities are maintained in vertical ducts, condensation is seldom noticeable, but in horizontal ducts it is more frequently observed. If horizontal ducts have a slight pitch to a convenient low point, such as the bottom of the fan housing, a small drain installed here will enable condensed vapors to be removed before serious corrosion (the most serious result of condensation) is caused.

Duct Dimensions. Care must be taken in the dimensioning and arranging of ventilation ducts if several hoods are exhausted by one fan. Difficulties are more likely to be experienced with

low velocity than high velocity systems. If the ducts are properly designed so that uniform velocities are maintained in all parts of the system, and temperature and gas density differences are avoided, these difficulties are less likely to arise. If hoods at different levels are connected to a common duct, it is necessary to operate the fan whenever any of these hoods is needed and that means high power cost, and even if these hoods draw properly when the ventilation systems are in operation, it is not always possible to stop the evolution of objectionable gases when the fans are turned off, and, consequently, the downward flow of a heavy gas or the rise of a light gas from one floor to another may take place. Similar difficulties of mixing of fumes from different points of the laboratory may be experienced if a number of ducts or fans discharge into a common duct or outlet, or when natural and forced draft systems are combined in one laboratory. Gases may rise in one hood and descend in another in a different part of the same building. If it is necessary to have low velocity systems with common ducts and fans or combinations of natural and forced draft, it should be kept in mind that the strongest and most continuous outward movement should be at the point of maximum concentration of objectionable fumes. If, for example, a laboratory is equipped with both hood and secondary ventilation, such as was described in Chapter IV, the static pressure produced by the hood exhausters should be greater than that of the secondary system. A high velocity system eliminates practically all these difficulties incidental to low velocity systems.

Large General Fans and Small Individual Hood Units. It is at once obvious that one solution of the problem discussed in the preceding paragraph is to have each hood or duct on a separate fan or, at least, to have only a small number of hoods in the same room on one fan, and have each fan discharge through its own individual duct to the outside air. This method of utilizing a large number of small fans, separately controlled from the hood they are evacuating, seems to be in general the method of ventilation most desirable. The obvious objection to this very effective and efficient method of removing chemical fumes is the original cost of the installation of the ventilating equipment. To offset this increased cost, there are, however, a large number of advantages which, in the case of several

modern laboratories, have been sufficient to outweigh the extra expense. In the first place, economy of operation can be effected. If a laboratory is equipped with a small number of large general ventilating fans to draw from hoods in various parts of the building, the practice in the operation of the laboratory will be to turn on all these fans during all of the time that any part of the building is in use. If a considerable number of small units are installed and controls are provided near the hoods, the worker in charge of the laboratory can use these fans when they are needed for the particular work in hand, and shut them down as soon as the work is completed. In this a saving in the total amount of current is effected. While so many variables are involved that it is impossible to give exact figures covering the different costs of large units and small ones, it is evident from the operation of the ventilating system of a laboratory with which the writer is familiar, that the expense for electrical power is one-half to two-thirds less than it would be for the use of large fans. Another economy which is effected by the use of small as compared to large fans, and one of which the chemist is likely to lose sight, but of which an efficient building superintendent will remind him, is the unnecessarily large amount of heat energy required to keep a building warm if air is being removed by fans at points where it is not necessary.

Natural Draft. In the ventilation of modern buildings, too little attention has been paid to the efficient utilization of natural ventilation, that is, the movement of air produced by the temperature differences naturally found in such buildings, or by natural air movements outside the building. Another means of producing air movement that has possibilities, frequently not utilized, is artificially heating air in stacks, thus causing it to rise. The fireplace of our forefathers and of our alchemical predecessors was a rather inefficient heating device, but a very effective means of ventilation. There are, however, serious objections to natural ventilation of a chemical laboratory. The chief objections to this type of ventilation for chemical hoods are danger of explosions and fire when inflammable substances are being discharged into a hood, the relatively low air velocities that can be produced through the vertical heights, necessary to reach rooms not adjacent to the roof, and the difficulty of

producing air movements through a duct which does not lead in a direct vertical line from the hood to the outside air. The chief advantages of such systems are simplicity and cheapness. While, as previously stated, it is hardly to be expected that natural and warm air ventilation can provide all the air movement necessary in a modern chemical laboratory, such cheap and efficient methods should be used where possible to supplement forced draft. One way in which this has been done in a well equipped research laboratory is to distribute fresh air under very slight pressure to each room from which it finds its way to the outside through separate 10 in. vertical tile ducts which have openings at the bottom and top of each hood. When a burner is placed in the lower part of the vertical duct, the volume of air withdrawn from the hood compares favorably with any low velocity exhaust system. Such an arrangement has the advantage of producing a certain amount of natural movement even when fans or burners are not being used. Hoods connected through individual fans and outlet ducts are more regularly ventilated by natural means during periods when fans are not running than hoods exhausted through large fans and common ducts.

Upward vs. Downward Draft. Consideration of the relative merits of up and down draft ventilating systems has seldom been given by laboratory builders. Space in the attic of a laboratory is generally considered the least valuable of any in the building and is the natural place to locate exhaust systems as the general assumption is made that the waste gases and vapors of a laboratory tend to rise. While this is true, it is due to the temperature of the diluting air and of the objectionable fumes and not to their normal densities. Nine of the ten most objectionable common gases and vapors are heavier than air when cooled to the same temperature. Ducts exert a cooling effect upon gases, and unless relatively high velocities are employed there is some natural tendency to retard the upward displacement of dense gases and vapors after they reach the ducts. In one large industrial research laboratory, an apparently successful attempt has been made to utilize this natural tendency of common objectionable vapors to sink, and at the same time secure the benefits of natural draft, referred to in the preceding paragraph. The laboratory in question has hoods on

two floors from which lead ducts connect to a common tile collecting-duct in the basement. This tile duct increases in size according to the number of connections as it passes from the front of the building toward the rear, where it connects to a lead covered fan and then to the bottom of a tall chimney into which the fan exhausts the objectionable fumes. When the fan is not running, the tall stack creates an appreciable natural draft through all the hoods in the building.

Fan Types. The type of fan to be used is largely determined by the factors that have been mentioned in considering the relative merits of high and low velocity systems. For low velocity systems, sheet steel fans and housings, protected by some common metal paint, are usually employed. The fans used are similar to those employed for general ventilation, and have a large number of small blades. Special alloy steels are now available for the construction of fan units to be used in chemical laboratories, but as yet most of the materials suggested are somewhat expensive. Special protection, such as rubber coating, plating and painting, enameling, coating with aluminum paint, etc., have been tried with some success in different installations. For certain gases, fans and housings made of bronze have been found to serve successfully, but for general chemical uses, copper alloys are not desirable. It should be borne in mind by the builder of a chemical laboratory that the problems to be met and overcome in the designing of equipment for the ventilation of a laboratory for general instruction or research investigations are much greater than those to be met in industry, which, although it may handle greater concentrations of corrosive materials, is usually dealing with one material at all times. The materials in an ordinary chemical laboratory must be chosen to resist any and all corrosive substances. For high velocity air installations, it will be necessary to provide high velocity fans. This, of course, limits the diameter of the propeller which can be used, and makes direct connection between the motor and the fan a more usual arrangement. For low velocity fans, belt reduction, silent chain drive, and even gear reduction have been made use of. High velocity air is quite commonly handled by means of fans in cast iron housings. These have been found to last a number of years, and if properly protected by a composition paint, constitute a practically per-

manent installation. Lead covered or coated fans have been used in some laboratories, monel metal or aluminum propellers and housings are also used, especially in small units, but considering both first cost and maintenance, ordinary cast iron is probably the cheapest material that can be used in a fan for high air velocity. Small fans made of chemically-resistant cast iron are on the market and serve very acceptably for the ventilation of acid vapors. As a rule this type of fan is quiet in operation, and, if the bearings of the fan are properly protected, last almost indefinitely. With this material, as with some other desirable materials, the chief objection is the high first cost. In order to prevent the contact of corrosive gases with a fan, it has been found possible to use the injector principle of removing gases from hoods and chemical apparatus; that is, high velocity clean air is injected by a fan into a duct that leads into the main duct at an acute angle. The rapidly injected clean air must draw along with it and force ahead of it the contaminated air in the main duct.

Special Problems. Some operations carried out in a laboratory produce high concentrations of very corrosive vapors. The most familiar example is sulphur trioxide from Kjeldahl digestions. This material and other similar substances are conveniently collected in a special silicon iron, lead, or glass duct in a soapstone hood and withdrawn by means of a silicon iron fan and duct. A typical arrangement is shown in Figure 33. The high concentration of water vapor over steam baths, cleaning vats, etc., is frequently handled by special ducts which open just above the bath and thus prevent condensation in hoods or on walls of rooms. (Figure 45.)

CHAPTER VI

LIGHTING

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Natural Lighting

Effect of Surroundings. A few moments' reflection will make it evident that the surroundings of a building must necessarily have considerable effect on the intensity of the daylight which reaches the interior of a laboratory. This effect was mentioned briefly in Chapter III. If adjoining buildings are of dark materials and of ordinary height, say three or four stories, and located within 100 ft., there is certain to be more or less interference. Little can be done about such interference once the position of a group of buildings has been fixed, although if it is possible to change the exterior color of adjoining buildings from dark to light, much improvement can be effected. Nearby trees and shrubs, which extend any distance upward from the surface of the ground, interfere somewhat with the natural lighting, but there are other compensations for the presence of such vegetation, which, in general, make it undesirable to have it removed in order to improve the natural light. Stretches of light colored ground, cement roadways and walks increase the light reaching a laboratory, but if they are located on the sunny side of a building, much objectionable, intense reflection may be produced.

Windows. The size, position, and arrangement of windows are also matters related to architectural effects as well as to natural light supply. As was mentioned in Chapter III, one of the characteristics of modern building is the increased use of exterior glass surfaces. Chemical laboratories do not show as radical developments in this direction as industrial buildings, but

it is not uncommon to observe laboratories where between one-third and one-fourth of the exterior walls are occupied by windows. Stated in another way, laboratories frequently are lighted by windows which occupy one half of the wall space above working table height. As has been previously indicated, in order to make the best use of natural lighting, the long axis of a building should be in an east and west direction. In the north temperate zone north light is most useful, and south light is preferable to the more widely varying east and west light. Frequently a larger window area is found on the north side of a building than on other sides. Solid panels of glass, extending entirely across the north end or side of a room, can be very advantageously used in certain special laboratories. The kind of window sash, and the number and size of panes of glass have considerable effect on the amount of light admitted through a given opening; as mentioned in Chapter III, steel sash are to be preferred from this standpoint. For microscopic work and the exact reading of volumetric apparatus, the cross bars of a window sash may be objectionable. While in general, ordinary window glass, whether ordinary weight, double strength, or plate, is satisfactory, an up-to-date laboratory should make some provision for the admission of ultraviolet light for the study of photo-chemical reactions. For this purpose, transparent, fused quartz glass is ideal, but almost prohibitive in price. However, at least one well-known maker of laboratory glassware is now offering relatively cheap sheets of glass which transmit ultraviolet light with an efficiency of over 90% of that of quartz. The ultraviolet transmission of this glass is reported to decrease less rapidly over long periods of time than is the case with certain varieties of imported glass designed for the same purpose.

Overhead Lighting. It is evident that thus far our discussion has been concerned with vertical window surfaces on the walls of buildings. In laboratory as well as in industrial construction, an increasing use of skylight illumination is being made. As a supplement to horizontal illumination, this is a very commendable development. The acceptability of overhead illumination is a point of considerable difference of opinion among chemists who have worked in laboratories lighted in different ways. The debate is, however, more concerned with the psychological satisfaction of the worker than with the effi-

ciency of the illumination. There is little doubt that adequate, general vertical illumination has certain inherent points of superiority, and few disadvantages as compared to horizontal illumination. The writer cannot venture to decide this question for each chemist, and suggests that those interested try the tests suggested in Chapter II. However, it seems to be the general opinion that for large classes of students who spend a relatively short time in the laboratory, the newer skylight or saw-tooth methods of illumination may serve acceptably, but for more advanced workers, for industrial and research investigators, horizontal illumination is generally preferred. The upper floors of buildings, including the attic, are sometimes used for large general laboratories. Such laboratories are generally lighted and ventilated by means of skylights. This practice frequently lowers the cost of construction and provides cheap and reasonably efficient ventilation and lighting. The skylights employed in this way may well be constructed in the form of a rectangular or cubical enclosure with glass sides, so that the direct sunlight is not admitted to the room below. Skylights opening over laboratories and lecture halls, but not necessarily saw-tooth panels, should be doubly enclosed, with considerable distances between glass surfaces to provide for heat absorption, and at least one layer of glass should be translucent or arranged to produce light diffusion. Other difficulties which are frequently met with in all glass skylights are leaks, breakage from snow and ice, and the need of employing special blinds to darken rooms in which the skylights are located.

Diffusion of Natural Light. Light diffusion in a laboratory can be aided by special panels of so-called prismatic glass, and by the use of partitions of similar or ordinary glass. State and municipal requirements for the natural lighting of toilet rooms and other special rooms, placed in the interior of the building, can usually be met by means of glass panels or partitions. The use of glass transoms and doors aids in the lighting of corridors and in increasing the illumination of a room which has windows on only one side. In large buildings, more careful consideration must be given to natural light diffusion than is the case with smaller buildings where the ideal arrangement of having windows on more than one side of larger rooms is possible. The width of rooms, which it is possible to illuminate

from windows on one side, depends on a number of factors such as the height of the ceiling, the area of the windows, color of walls and ceiling, and the direction from which the light is admitted, but, under favorable conditions, it is generally considered to be difficult to provide satisfactory natural illumination over a greater distance than 20 ft. from a window.

Artificial Lighting

General Tendencies. Increasing demands by laboratory workers and builders are being made upon the electrical engineer responsible for the installation of artificial lighting. Several important, general tendencies are noted in modern lighting practice. Among these can be mentioned: first, increased intensity —buildings which were considered adequately lighted five years ago now appear gloomy by comparison with recent installations; second, increase in the size of the units, due largely to the superior efficiency and longer life of the large, gas-filled, incandescent lamp; third, increased use of indirect lighting, including general and flood effects; and fourth, daylight duplication or attempts to reproduce the wave length distribution of natural diffused light. Commenting somewhat more fully upon these developments will serve to introduce many of the important considerations that the chemist should keep in mind in his cooperation with the electrical engineer, but before taking up further discussion of these points, substitutes for electricity may be worthy of mention. Gas, natural or artificial, may in certain special localities be used for artificial illumination as the modern mantle has made possible a light of satisfactory quality. In a few cities, it is reported that gas lights are required over exits, and for emergency uses. The use of mantles with gasoline and other volatile liquid fuels has made it possible to use portable lights for certain special purposes, but the perfection of small, automatic electric generating units makes it possible for even the smallest and most remote laboratory to have a supply of electricity.

Intensity of Illumination and Size of Units. Statement of the intensity of illumination is usually made in terms of foot-candles at the level of working surfaces. Such statement of foot-candles may be the result of calculations based on rated candle

power of bulbs and heights above working surfaces, or of direct photometric observations. Marked divergence between these methods is noted; actually observed values being less than the calculated. A maximum intensity is usually required for laboratory observations. Certain special portions of a laboratory may demand especially high intensities, but in general an intensity of from 10 to 15 calculated foot-candles has been found to be satisfactory in recently constructed laboratories. For the general illumination of offices, class rooms, lecture halls, libraries, store rooms, and corridors, intensities of from 3 to 6 foot-candles are considered satisfactory if supplemented by increased intensities on reading tables and lecture desks. A number of factors influence the efficiency of illumination other than the actual photometric reading or calculation based on candle power and distances. One of these factors is the second point referred to in the first paragraph under the heading of "Artificial Illumination" in this chapter, namely: the increased size of individual units. In a room of sufficient size to require several light fixtures, more uniform, general illumination, and more agreeable light at any particular point can be secured by the use of larger units at considerable distances from the working surface. For example, in one elementary laboratory it was found that fifty students were working in a room having an area of approximately 1,000 sq. ft. This was illuminated by fifty lamps of 50 watt rating placed a short distance above the working space allotted to each student, making a total of 2,500 watts required for the room. A change to fifteen 150 watt units, suspended a few feet below the ceiling, increased the general illumination and decidedly improved the comfort of the students with a saving of 250 watts for the room. In general, there seems to be little doubt that the change from small units to large units improves the quality of artificial light. Other objections to the use of small units are the loss of bulbs, since fixtures are usually hung within reach of workers, the lower candle power efficiency, the shorter life of small bulbs, and the greater expense for installation and maintenance of the larger number of fixtures.

Indirect Lighting. A continuation of the development which introduced the large in place of the small unit is responsible for the increased use of semi- or totally indirect light. The success of this method depends upon the light-reflecting properties of

ceilings and walls. From the standpoint of actual foot-candles per watt of electricity, this method is somewhat more inefficient than direct lighting, but the absence of eye strain and the greater ease and speed with which certain instruments can be read in considerable measure offset this inefficiency. Several standard makes of indirect and semi-indirect fixtures are on the market, and these are found very useful in class rooms and lecture halls. From direct fixtures in a class room of ordinary ceiling heights, a considerable intensity of direct light falls on the retina when the eye is looking at objects in a horizontal plane, and the eyes of the teacher focused on the student, or the eyes of the student directed toward a blackboard are more tired at the end of a period if direct lighting is used than if semi-indirect fixtures are used or the room is lighted by reflection from the ceiling. In the past it has been a common practice to place a small light directly over each balance in a balance room. In addition to the objection of the unequal expansion of the balance beam that may be produced by the proximity of the light bulb, objectionable shadows are almost always caused on the beam pointer scale. Generally diffused or, better, totally indirect illumination is decidedly more acceptable.

Daylight Duplication. The desirability of securing an artificial light of the same intensity and wave length distribution as naturally diffused light has been caused largely by demands for color matching of industrial products. Mercantile establishments have long been desirous of enabling the purchaser of a colored article to be confident that the color he has chosen by artificial light will be the same by natural light. As a result of these demands, several types of fixtures, providing daylight duplication in a greater or less degree, are on the market. In general, these consist of diffusing globes containing one or more layers of blue glass to increase the relative intensity of light of short wave length. Somewhat more scientific units combine this principle with reflection from a series of mirrors, designed to increase the quantities of blue and violet light. The efficiency of the lights producing the best daylight duplication is not so great as that of ordinary fixtures, but the effectiveness of such light is more marked than photometer readings indicate. The use of such fixtures is to be recommended for all rooms where titrations and exact color matchings are to be carried on.

Fixture Materials. The material of which light fixtures are made should be given some consideration by the chemist. Ordinary, light-colored, lacquered brass is readily attacked by chemical fumes. Enamels and corrosion-resisting paints are satisfactory, and the use of aluminum, whether as a protecting paint or as a material of fixture construction, is highly desirable. In certain rooms, it is also desirable to protect the light bulb by enclosing it in a gas-tight receptacle similar to those used on shipboard. Suggested locations for such protected bulbs are inside of hoods, in hydrogen sulfide rooms, and in storage battery rooms.

Switches and Outlets. The distribution and control of the current for artificial lighting is largely a matter for the electrical engineer. The chemist must accept some responsibility, however, for deciding upon the location of switches, and wall and desk outlets, as well as for the location of the outlet boxes to which fixtures are attached. In laboratories, fixtures should be placed so that direct illumination will fall upon the entire working surface and all objects ordinarily placed thereon, without interference of shadows of any kind. Whether the lamp is placed over the worker or the aisle will depend upon the fixture used. The special needs of illuminating the wide variety of apparatus and equipment used in a laboratory are too detailed to discuss here. It is suggested, however, that the potential user of a laboratory give some time to careful consideration of the way in which his equipment should be illuminated and the most convenient location for switches and outlets. In general the number of the latter should be ample. The increasing use of electrical devices of all kinds makes it almost impossible to have too many outlets. The employment of the so-called three-wire switches—that is, switches which turn on at one point and turn off at another—is an aid to conserving electricity as well as energy of laboratory workers. Remote control switches also make possible the saving of many steps. At the present time, the snap type of light control switch is most popular, but in recommending electrical fixtures and switches, it is difficult to predict the improvements that may be expected within a very short time. In certain locations in a building, ceiling switches, controlled by cords, hung at convenient heights in rooms, are very useful.

Distribution of Current. Conduits. Conduits of steel or wrought iron pipe are almost universally used for the protection of electric conductors. For lighting circuits, these conduits are usually permanently embedded in the masonry of walls and floors. In general this practice has no special difficulties in a chemical laboratory. It is well, however, to avoid having conduits on outside walls, since in a few cases it has been found that condensation within a cold conduit has caused breaks in the insulation. The chemist should insist that the electrical engineer provide conduits of adequate size; that is, somewhat larger than the sizes used in standard electrical engineering practice. If this is done, it is possible to install wires in conduits without seriously injuring the insulation, and if, for any reason, wires need to be withdrawn, this can be done without difficulty. Other details of distribution, such as the installation of a sufficient number of pull boxes, panels, and control cabinets, can be left in charge of the electrical engineer. It is, however, advisable for the chemist to point out that in a laboratory a maximum flexibility of circuits is desirable, frequent extensions and replacements are necessary, and that corrosion is likely to shorten the life of the wiring installations. It is certainly desirable to have several extra switches and conduits leading from the main source of supply to distributing cabinets and panel boxes. It is well to make certain that adequate precautions are taken by the electrical contractor during the installation of electrical distributing systems to protect the interior conduits from moisture and building waste. It frequently happens that unless the user of the building insists upon it, panel boxes and control cabinets will not be equipped with master-keyed locks. Attention should also be paid to the need of having each circuit adequately marked, and complete diagrams of the wiring system left with those in charge of the building. Regarding the devices to be used as lighting equipment, little dissatisfaction is likely to arise if samples of each are inspected before purchase. This applies with special force to innovations. It is well, however, to bear in mind that certain recently introduced materials are very acceptable in a laboratory. Among these may be listed aluminum fittings, conduit elbows and conduit, and new composition materials to replace slate for switchboard and control panels.

CHAPTER VII

LABORATORY TABLES

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We have discussed in earlier chapters the types of buildings and the arrangement of their different parts, the rooms needed and their location with respect to each other. We come now to a consideration of the contents of the various rooms. We might first outline all of the different things needed in the whole laboratory and then discuss these in detail. However, since there is a great diversity of opinion as to what should be put into a laboratory it was thought best to consider in this chapter those articles of equipment found in all laboratories, namely, the working tables. In later chapters the equipment will be considered under the titles of the branches of the subject for which the rooms are to be used.

A Laboratory Table. All chemistry laboratories are equipped with tables on which the work of the laboratory is to be carried out. The name *table* is used here rather than *desk* since the latter word has more specific reference to the article of furniture of that name found in offices and libraries, and the device used in a chemical laboratory is classed as a table in shipping by freight, hence its use here. A laboratory table is a piece of furniture which is put into the laboratory to facilitate chemical work. A chemist uses many tools and many reagents and he must have a suitable place for doing this work. He must also have conveniently at hand running water and gas and waste-pipes, electric current outlets, etc. A laboratory table which really serves its purpose will give the worker a convenient arrangement of all these requisites so that his work may be facilitated in every way. The tables should have incorporated

in them whatever has been found excellent in service. Utility is the main consideration and this should be coupled with permanence under the severe test of continued use. Then, too, the tables should have a neat and stable appearance, for they should give the student ideas of neatness and solidity.

Subject to Hard Usage. Laboratory furniture must be quite different from that used in homes, offices, and public buildings. Commercial furniture for these latter uses is under constant care and is always protected from disturbing conditions. Laboratory tables as well as other furniture are subjected to unusual conditions. Water, acids, and other chemicals are continually used and are often spilled upon the table tops, and these corrosive agents sometimes get into the drawers and cupboards as well. The exterior case work is subjected to the fumes of the laboratory. Heavy equipment of metal or glass is set upon the table tops. All these conditions bring about the necessity of using tables which will withstand such treatment.

Variety of Tables. It is manifest that the different branches of chemistry would best be served by different forms of tables, or at least modifications of the general type or form. Conservation of space would lead to a minimum unit of table space and a minimum unit of table front per student. A study of working conditions for the persons of average height would lead to a standard of height. The necessity of having reagents on the table before the student, the commodities, such as water, gas, steam, electricity, etc., piped to the table, the size and arrangement of the drawers and cupboards, the side tables, and shelves —all these might call for variation according to the branch of the subject or the extent of the courses offered.

Use of Tested Forms and Materials. There is much difference of opinion in regard to the shapes, sizes, materials, and equipment of laboratory tables. For some items there are standards which are quite well established. Many new forms have been presented to would-be purchasers and many of these have actually been installed without sufficient previous testing of their suitability and permanence. It is worth while to make experiments with new forms and to try them out in actual use, but it is very unwise to risk the whole equipment of a laboratory on untried or unproved forms of tables. After severe trial for from five to ten years in single rooms where groups of stu-

dents are working we shall know whether or not they are satisfactory as to form and materials.

Tables Well Standardized. As has been said, there is much difference of opinion in regard to many details about laboratory tables. But there is quite universal agreement in regard to some dimensions and equipment and these will be considered first. A table height of thirty-six to thirty-nine inches and a top width of forty-eight to sixty inches and a spacing of four and a half to five feet between tables are units which are generally used. Of course, one can vary from these dimensions, but much of a variation may bring about unsatisfactory conditions. Smaller dimensions crowd the work and larger ones decrease the student-capacities of the rooms. These sizes give good working conditions without crowding. There is no objection to larger units for either the aisle or the table depth except this taking up of more space per student. It is, of course, understood here that the dimensions given apply to tables set out in the room with aisles between them, which is the universal method of building tables for laboratories in which groups of students work. In these the students work at both sides of the tables. Some tables are made with students working only on one side of the tables and some are built along the walls of rooms. The latter are usually constructed as half of one of the room tables, with a top width of twenty-six to thirty inches to allow for sinks, plumbing, and bottle racks.

Height of Tables. Three feet is the average height given to tables. Some build tables thirty-three inches or forty inches in height. Forty inches is too high for the average person, particularly if it is a co-educational institution. A high school table might be made with a height less than thirty-six inches without inconvenience to the average high school student. One college for girls has tables forty-four inches high, but they work as though on shelves. The only advantage gained in this case was that the cupboards would accommodate ring stands thirty-six inches high—it was the sacrifice of the girls' convenience to that of the ring stands. Thirty-three inch tables cause too much stooping on the part of tall students. All tables should be provided with a toe-space at the front, to enable the student to get nearer his work without defacing the furniture.

Depth of Tables. A table depth of two feet on each side

gives a good working space for the student, who can easily reach over this depth for reagent bottles placed at the center of the table. Naturally, still deeper spaces are used for tables for special uses, but the figures here given are for ordinary college and university laboratories for general, analytical, organic, physical, physiological, and electrical chemistry. For special and research laboratories different depths are sometimes used.

Fig. 37. Double Table of Trough Type.

Aisles. Though the standard distance between tables is five feet, there are many laboratories where the tables are placed from four to four and one-half feet apart without serious inconvenience. It is largely a matter of the length of the tables used. Where six foot units are installed, four feet between the tables is ample space. Where nine to twelve foot tables are used, four and one-half feet is adequate aisle-space. For longer tables, eighteen feet and upwards, it is better to use five foot aisles as the traffic in the aisle between tables increases in proportion to its length. Often these figures have to be modified to suit the dimensions of a room which was planned and built before the tables were planned and located. Of course, it is far better to proceed in the other way and make the dimensions of the room suit a certain number of tables.

Variables—Forms. The common and economical practice is to have all tables double in the larger laboratories using the sizes already given. Some older laboratories and a few where space and cost did not seem to figure use desks with the students facing in one direction. This is wasteful of space, but it might be argued for this arrangement that the tables may have

a better arrangement with respect to lighting of the room and all students will face the instructor without turning about when he wishes to have their attention. Certain tables of this type serve well in high school laboratories which are used both as a laboratory and a class room or a study room. In small rooms, tables are usually constructed along the wall and are approximately like half-sections of the double tables. They are usually made thirty inches deep as the shelving necessarily must be wholly over this half-table and would interfere with the available space if the table should be only twenty-four inches deep.

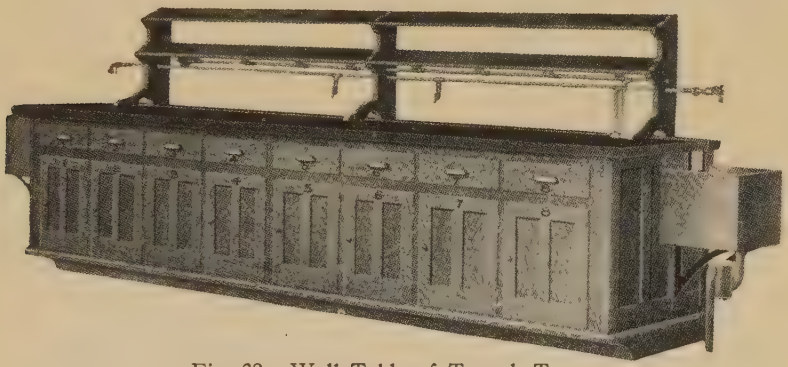

Fig. 38. Wall Table of Trough Type.

Table Lengths. Tables are standardized to some extent in six-foot lengths and the multiples of this length—twelve feet, eighteen feet, and sometimes twenty-four feet. Twenty-four feet in length produces inconvenience in getting about the room and passing other students between tables. Certainly tables should never be more than twenty-four feet long. Variations of three feet in length are often used because of room widths calling for these intermediate lengths. This would give tables of fifteen feet and twenty-one feet or possibly in some cases a table nine feet in length. It simplifies the manufacture of tables to call for multiples of six feet.

Spaces at End of Tables. There is a difference of opinion as to the space which should be available between the ends of the tables and the walls of the room. Some prefer to run the tables to the wall at one end and leave an aisle of from five to seven feet between the other end and the wall. This is satisfactory if the room is not wide and the tables do not exceed twelve to

fifteen feet in length. Where tables are from eighteen to twenty-four feet long an aisle at both ends of the table is recommended. In this case some would have a passageway of about eighteen inches at one end of the table and an aisle of from five to seven feet at the other end, though the eighteen-inch passageway would seem to be too narrow for practical use except as an emergency exit. Still others prefer the aisles at both ends of the same width or approximately of the same width. An aisle space of seven feet at the end will permit of wall hoods being located here or they may give very good space for reagent shelving if desk hoods mounted on the tables are used. Some would put fume hoods at one end of the tables extending out about three feet or forty-two inches from the wall, using this part of the table top as the hood floor. Where tables are so spaced that they do not come in front of windows, a plan quite frequently used is to mount the upper structure of wall hoods on the table top at the outside wall end. This does not cut off an appreciable amount of light, and when the hood structures are not over three to four feet wide, they present an orderly arrangement in the room. In this way a section of the hood is available for each group of students working on one side of the table. These hoods would be of the double type with a working section on either side of the table. Some have used these hoods only on alternate tables, leaving a passageway about the ends of the others. In the case of a very wide room with two rows of tables, the center aisle between the tables should be at least four feet in the clear. However, if reagent shelving, with a waste compartment underneath, is placed in this aisle, it must be made correspondingly wider.

Space per Student. There is also considerable difference of opinion as to the width of table front which should be given to each student and considerable difference in installations. In general, the space per student of what we may call the table length per student varies with the subjects for which the tables are used. A first year student in general chemistry does not need as much room as a student in organic chemistry. For this reason most manufacturers make tables with varied locker space for different laboratories.

The usual lengths of table space per student are three feet, three and a half feet, and four feet. Three feet is the size usually

used for first year students in general chemistry, while three and a half feet is a size used for other laboratories except for research laboratories where six-foot lengths or more may be occupied by one student. Some plan a three-foot unit and then do not work students on every unit at the same time. For example, an eighteen-foot table would care for six students on each side, giving each three feet, but only eight students are worked at such a table at one time and thus each student would have a table space of four and a half feet. If five were put on one side of this table at the same time, each would have a little more than three and a half feet of working space. Since it is perfectly feasible to thus vary the working space, it is quite easy to use tables standardized as to their length, providing the room width permits this to be done. It is very wise in planning a new building to make room widths suit standard table lengths.

Materials. (The Body of the Tables.) The materials used in the body of laboratory tables vary considerably. The best makers of tables use oak wood in their construction, and nothing has been found which will give better or longer service. It is not necessary that this be quarter-sawed and given a piano finish, and yet it is quite essential that the table shall have a neat appearance as well as a long and useful life. The panels are made of three or five-ply veneer—the latter being much the better. A high grade of glue must be used in the manufacture of these panels. Such highly ornamental woods as walnut and mahogany, and tables of metal are sometimes used. The metal tables are liable to be attacked by the corrosive fumes of the laboratory, unless carefully protected. The cabinet parts of tables should be finished with a coat of filler and three coats of cabinet rubbed varnish, sanded between the coats, or other equally durable filler. The wood may be stained to harmonize with the colors used in the rooms in which the furniture is to be installed.

Table Tops. Wood. As the table top is where the student and teacher constantly carry on their work, it, above all else, should be in proper form and give the best of service. Two materials are in common use for table tops, wood and soapstone. Wooden tops are usually made up of narrow strips, about three and one-fourth inches wide, most carefully glued together, and, best of all, with some spring device to continually exert a pressure to keep these joints together. It is not enough that these

strips be bolted together, for when once they expand with a rigid bolt and later contract, the bolt loses its effect. By using a spring on the head of the bolt or at each end there is a continual tension and therefore a holding of the strips together. Some, however, do not believe that this expensive type of construction is necessary, but use seasoned oak one and a quarter inch thick, laid flat side down. If the top is fastened only at the back, and is battened to slides toward and at the front, warping is impossible. The finished top should be about one and five-eighths inches thick. The wood preferred for these tops is birch, though maple and other woods have been used. Poplar, while it takes acid-resisting finishes well, is rather soft and does not resist abrasion as well as birch or maple. The upper surfaces of these wooden tops must be carefully prepared and given an acid-aniline treatment, for which a formula is appended.

ACID-PROOF WOOD STAIN

Solution No. 1

125 grams of copper sulphate.
125 grams of potassium chlorate.
1000 grams of water.

Solution No. 2

150 grams of good fresh aniline oil.
180 grams of concentrated hydrochloric acid.
1000 grams of water.

Wood must be free from paint, varnish, grease or chemicals. Apply two coats of boiling hot solution No. 1 with a paint brush, allowing each coat to dry thoroughly before the next coat is applied. Then apply two coats of solution No. 2 in the same way. When the wood is completely dried, wash off excess chemicals with hot soapsuds. Finish with raw linseed oil. Polish comes from rubbing the oil down well with a cloth or sponge. Whenever the tables get dingy again go over them with a coat of linseed oil and rub smooth.

Makers of laboratory furniture are now able to furnish black table top finishes similar in appearance to the standard aniline black finish just described, but somewhat more resistant to heat and corrosive chemicals.

Wooden tops properly prepared in this way will give excellent service and will neither warp nor split open at the glued joints. One cannot be too careful in requiring the highest grade of workmanship for table tops. These tops are in use every day and much depends on having the best quality. To make tops of this kind involves so much work that the expense is about the same as it would be to use soapstone. Wooden tops are sometimes made of poorer wood and poorer construction, but they are more expensive in the long run than those here described. All woods used either in the making of tops or of the bodies of the table should be air-dried wood, cured with kiln treatment just before being made into tables or table tops. Wood tops give excellent service if a few precautions are taken in their use. When strong alkalis or acids are spilled on the tops they should be wiped up or neutralized quickly. Pools of water on the top should not be allowed to stand longer than necessary, nor should heaters be placed thereon which will reflect a great deal of heat on the table top during long periods of time. At intervals of two or three months, wood tops should be given a dressing with boiled linseed oil diluted by an equal volume of turpentine.

Soapstone Tops.[1] Soapstone is much used in the making of tops for chemical laboratory tables, and these tops give very good satisfaction and service. The soapstone is sawed into slabs about one and one-quarter or one and one-half inches thick, and of suitable size for handling in setting up the tables. Care must be taken to select stone without calcite streaks which would disintegrate rapidly from acids. The upper side is polished and the slabs are joined together so as to keep them in position and present a uniform surface. Like all other good things, both the wood and soapstone tops must have intelligent care. Soapstone tops are sometimes condemned by teachers, but on going into their laboratories one readily discovers that they did not know how to care for stone tops. In numerous laboratories these are found covered with linseed oil preparations or similar coatings. Soapstone may be used satisfactorily without any treatment except sand papering during the Summer vacation

[1] By "soapstone" in this report, we mean a variety of serpentine marble very much harder and more refractory than ordinary soapstone, which is commonly known in this country by the trade name of "Alberene."

when there has been very bad corrosion. In the larger institutions electrically-driven sanding machines are used for this purpose, care being taken to select the proper sanding medium to fit the speed of the revolving disc-arm brush. As some treatment is desired, non-drying oils, such as light paraffin or a mixture of olive oil and kerosene or "Oildag" should be applied now and then, say once a semester.

Tile Tops. The newer type of glazed vitrified tile presents a very lasting and attractive top surface. A selection of high grade tile should be used, always vitrified. Whether a glaze should be applied over the vitrified tile depends on the person selecting the tile. Some object to the glaze, though on the other hand it adds to the density of the surface of the tile. There are now available several acid-proof cements in which the tile can be laid, which are as resistant as the tile itself. A soapstone border from two to four inches wide may be used around the edges for binding. This border is securely locked into the frame of the tile base itself, which is made of wood with suitable iron reinforcing bars extending through the top with a good concrete filler used to hold the bars in position. The tiles are embedded in this top with acid-proof cement. It must be said, however, that tile tops are considerably more costly than wood or soapstone.

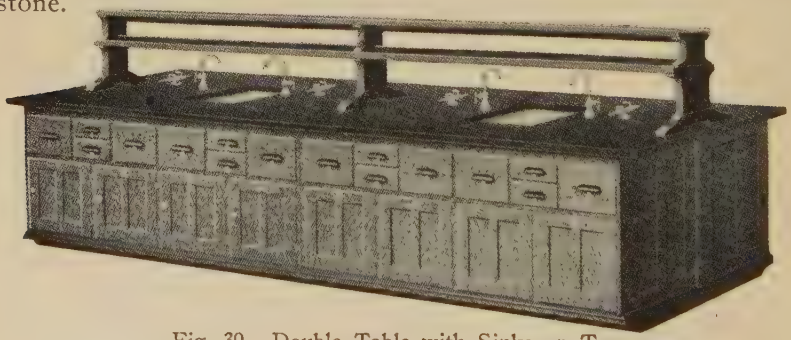

Fig. 39. Double Table with Sinks on Top.

Other Materials for Table Tops. There are other materials available for tops, such as slate or asbestos board, and recently there were put on the market several types of moulded tops. These latter are still in the experimental stage, but they represent possibilities and may be developed to the point where they will meet the severe service found in a chemical table top.

Sinks. The materials most commonly used for sinks are soapstone, acid-proof stoneware, pottery, and enameled ware. Soapstone sinks have been used very largely in later years, but the vitrified pottery and stoneware sinks are quite popular at present. The soapstone sinks must be made of stone slabs joined together, hence, they must have sharp corners, while in the stoneware and pottery sinks the corners may be made of any desired shape. These sinks, now made in a single piece, have no joints to leak, and the better makes are very resistant to the action of acids or bases or other corrosive substances and stand up well in usage. Both of these varieties of sinks are subject to breakage, but they are not often broken after being properly installed.

Enameled iron sinks are not subject to breakage, but are more subject to corrosion than the other varieties. A sink must be able to withstand sudden changes in temperature of the materials poured into them—such changes are hard on enameled sinks. As they are constructed of one material coated with another the expansion rates are different and give rise to trouble. Enameled sinks are more attractive than the others at first, but they become unsightly when corroded. At present the order of desirability seems to be: Stoneware or pottery sinks as first choice; soapstone, second; and enameled ware, third. In making this rating only first grade makes are considered, as it is possible to have a pottery sink which is not as good as an enameled ware sink.

Other materials are sometimes made into sinks such as lead linings put into iron sinks or even wooden boxes. Sometimes iron or similar sinks are coated with tar or asphalt. All of these are mere makeshifts and may serve in a temporary way, but are not desirable for permanent equipment. The chapter on plumbing will give detailed suggestions on this topic.

Location of Sinks. Sinks may be located in different places. Some are placed on the table tops and some at the ends of the tables. In some cases the working table tops and ends are kept free from sinks and they are placed in side tables or attached to the walls of the room. Where they are placed at the ends of the tables it is a common practice to have a trough running the length of the table at the center and emptying into the sinks at the end.

In first year laboratories a good arrangement is to have the sinks on the table tops and about eleven by seventeen by five and one half inches inside measurements. These serve students on both sides of the tables, and they may be used as pneumatic troughs. End sinks are usually made deeper and larger, for example, fifteen by twenty-four by twelve inches as a maximum, but smaller sizes may be used.

In any case it is wise to have a general sink to which cold water, and steam or hot water or both are piped. Demonstration tables should have a sink in the top of each table. This need not be large—say ten by fourteen by seven and one half inches.

When troughs running the length of the tables are used, they usually are made either of soapstone or lead-lined wood. The lead-lined troughs, unless painted, become somewhat unsightly but are, on the whole, a very satisfactory form. These troughs slope from one end to the other, not less than 1-100 of the length, and sometimes, from the center to each end in very long tables, though this has the effect of doubling the waste drains. They are made of different depths depending on the length of the tables, from four to five inches where the trough empties into the sink. Here there should be a serration or groove under the edge of the trough to prevent the water from running back under the trough.

Drawer and Cupboard Arrangements. There is great variation in the arrangement of the drawers and cupboards under the tables which are placed there for the purpose of furnishing storage for the apparatus used by the workers at the tables. Some want nothing but cupboards, and these as large as possible, while others want only drawers, but most want some kind of combination of both. Figures 40 to 43 illustrate a number of drawer and cupboard fronts. Some tables have a single drawer for each student with a single cupboard beneath, while others have two drawers and a smaller cupboard. Some have a deep and a shallow drawer, others have one wide and two narrow drawers with a small cupboard below, some have the whole space made into a cupboard but with one or more drawers inside the cupboard. Some have a bank of four or five drawers using the full length, and beside the bank, a cupboard using the full height. This cupboard contains pieces of apparatus used in common by all the students working at this table, while each

student has his own individual drawer. Some have a device which pulls out and which has racks and pins and holders on its sides for storing the apparatus. This device rolls out on a castor or castors and is pushed back under the table when not in use. These are only some of the numerous forms of drawer and cupboard arrangements which may be found in laboratories.

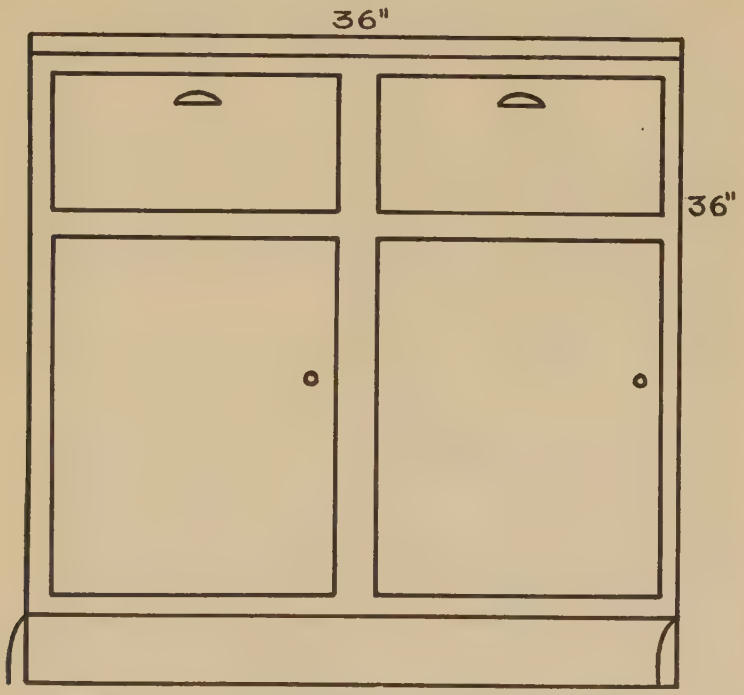

Fig. 40. Drawer and Cupboard Arrangement of Table.

The simplest arrangement for Freshman laboratory and a very satisfactory arrangement.

Three such divisions to 36 in. of top makes both cupboard and drawer rather narrow. With 42 in. as unit of top per student, three divisions like above can be used—in fact two divisions give rather wide drawers for 42 in. of top.

Serviceable Forms. An effort will be made here to indicate some table arrangements which have given excellent service. For Freshman tables a very good form is a single drawer about seven and a half inches in height with the rest of the space below as a cupboard. The width of such a drawer will depend on the general plan of the tables. If a width of three feet is given to a

working space this may be divided into either two or three units; three units, however, would make each somewhat narrow. If more than three feet of width is given to each working space, three units per working space will give wider drawers and cupboards.

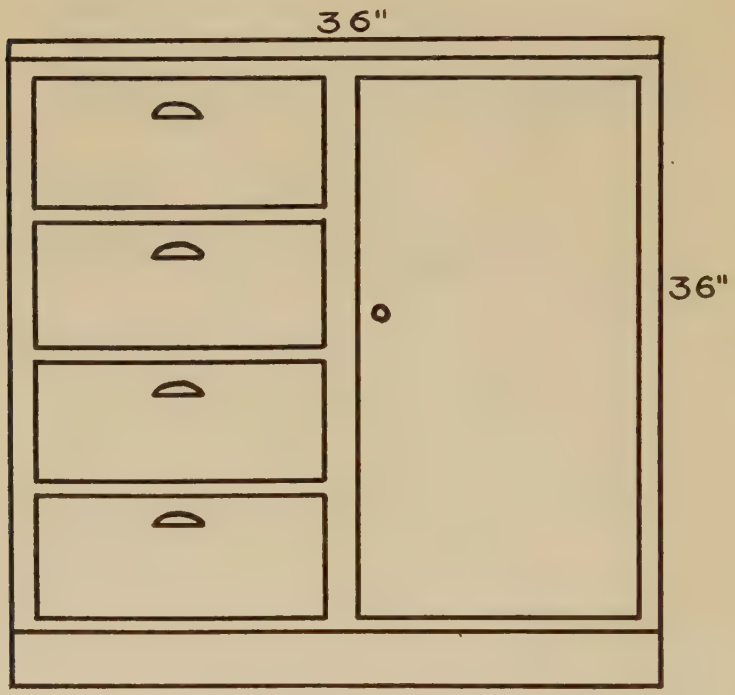

Fig. 41. Drawer and Cupboard Arrangement of Tables.
This permits working four sections at one desk.
Five drawers may be used without making them too shallow for use.
The cupboard is here supposed to be used in common by the four students.

For more advanced students an excellent arrangement is to have a wide drawer just under the table top with two narrow drawers side by side under this and a cupboard below. The narrow drawers extend across the whole table, thus giving a drawer over forty inches in length. Eight and a quarter by forty-one and a half by four inches are suggested dimensions for these drawers. One of these opens on one side of the table and the other on the opposite side. This arrangement is particularly good where the working space of tables per student is forty-two

inches or more,—each working space having two complete sets of drawers and a cupboard. In this arrangement the top drawer (suggested dimensions are eighteen by fifteen by four inches) takes care of all smaller articles while the deep drawer will hold burettes, condensers, and long tubes, and the cupboard (twenty

Fig. 42. Drawer and Cupboard Arrangement of Tables.

The smaller drawers extend through the table and will hold burettes and condensers. Where the blank appears above, the drawer opens on the opposite side of the table.

No better arrangement of drawers and cupboard has been devised than this for the work of students above the first year of chemistry. It may be used either with trough tables or with those having sinks on top.

A 36 in. unit could be used here but it makes the small drawers rather narrow.

by twenty by eighteen inches) will care for flasks, bottles, desiccators, etc. It is desirable for convenience that the long space for burettes, etc., shall be a drawer and not a fixed box inside. The drawer gives one access to its full length at any time, while the fixed box or tube gives access only at the end.

These two arrangements give very satisfactory results in actual use. Modifications of these which are not too drastic may be very good.

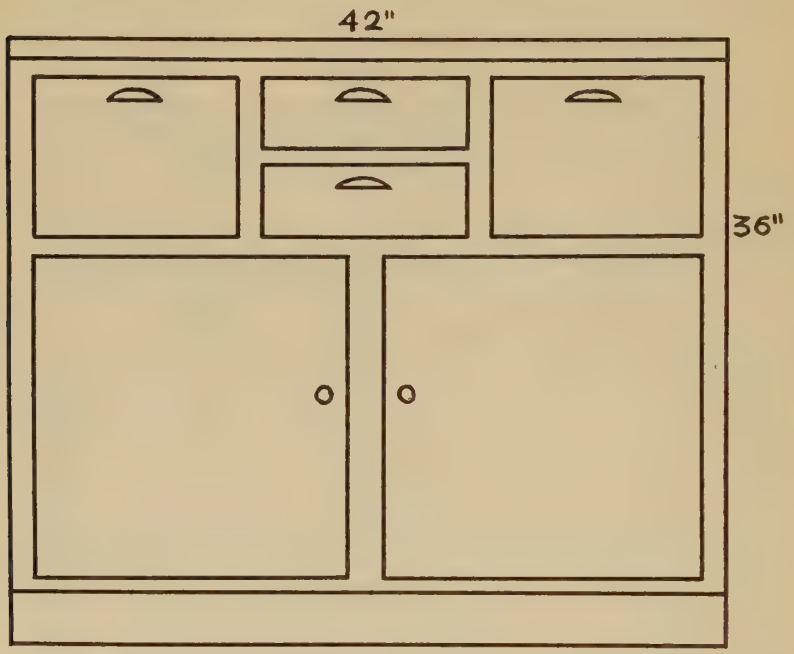

Fig. 43. Drawer and Cupboard Arrangement of Tables.

This is a standard type giving each student a high drawer and a shallow drawer. It gives more cupboard room than Fig. 42, but the advantage is not much in this respect.

This type may also be used with a 36 in. unit of top space without interfering with its usefulness.

These four figures are only samples of drawer and cupboard arrangement, but they represent very good arrangements.

Objections to Other Forms. Some of the objections to the other forms mentioned above may be noted. When a bank of individual drawers is used with a common cupboard, usually there is not sufficient space for the storage of apparatus; the storage of flasks for individual use is very limited, and responsibility for the apparatus in the cupboard breeds trouble. The form which has the whole storage part on wheels and which pulls out is difficult to move; if left out, it is in the way of workers; in actual tests it has been found to take considerably

more time to find apparatus than with the drawer and cupboard arrangement; it also gets out of order and sometimes mars the floor. In a few places the whole drawer and cupboard arrangement is made in units which can be withdrawn from under the table top and stored elsewhere while other units are put in place. The purpose here is to provide storage containers for a number of sections and keep the laboratory in use all the time with sections coming and going. This has not proved a practical method. It is unwieldy, takes much time and work for the changes, and the removable parts soon become unsightly.

Some laboratories have arranged their desks with a modification similar to the one described but without the notion of changing the drawer and cupboards except to remove them when the plumbing needs attention. The plumbing in this case is all attached to a central frame and the table tops and shelves. The drawer cupboard parts are then pushed in under the tops but were not made a fixed part of the table. The advantage in such an arrangement is very slight outside of getting at the plumbing, and this may be otherwise arranged on most of the forms in use.

Here again attention should be called to the fact that standard, well-tested forms of drawers and cupboards in various combinations are made by all good manufacturers, and will fulfill practically all requirements.

When sinks are placed on the table tops it is a convenient arrangement to put a cupboard opposite the sink, making a single cupboard of the whole height. This cupboard may be used to contain ring stands or other taller materials which are to be used in common. Some have used this cupboard as a location for waste crocks, but this is not a good use to make of the space.

Ordinarily cupboards, excepting those below sinks and some other general forms, should have a shelf on one side and on the back. If the cupboard is quite wide shelves may be put on both sides and on the back. These should be only four or five inches wide except in the very wide cupboards.

The cupboards beneath the sinks give opportunity to make arrangements so that the plumbing may be reached from the back of the cupboard. This back may be removable and thus give immediate access to the traps under the sinks and to the other plumbing near that location.

Drawers should have tenon and groove construction both in front and back. All drawer bottoms should be completely housed in and the bottom should be made from cross-band laminate stock. The sides should have an extension beyond the back as a safeguard against dropping a drawer and its contents when pulled out.

Locks. Different systems are used for locking the cupboards and drawers. A convenient method is to have internal devices for fastening the drawers which are operated from within the cupboard. A lock is then put on the cupboard door and the one lock thus closes the whole student unit. Another method is to use a separate lock on each cupboard and drawer, but it is customary in this case to have a single key which will unlock all of the locks belonging to a single student unit. Very many laboratories have a key cabinet placed on the wall inside the room near the entrance, and each worker leaves his key in this cabinet between working periods, and the cabinet is locked by the instructor. This is much better than having the worker carry his key away with him when he leaves the laboratory.

Key cabinets are now constructed so that only the sections with the keys for a particular group are exposed at a time. All keys for other groups are kept locked within the board itself. These cabinets are now made commercially to provide for two to ten classes. Another desirable key cabinet is one that will hold all the room door keys of the whole building and may well be kept in the curator's office or in a vault. Laboratory equipment manufacturers build these cabinets of various sizes and it is advisable to procure a size that provides also for master keys and other special keys.

Some prefer to use keyless locks, which permit of hundreds of different combinations, are very serviceable and cost about the same as a good lock of the other variety. An eyelet is fastened to the door and another to the door frame so that the two eyes are exactly opposite when the door is closed and the keyless lock is inserted into the two eyelets. These padlocks do away with the key cabinets. A student may forget his combination but he never comes having left his key at his room as he often does when a key cabinet is not used. The instructor carries the combinations for all the keyless locks in a very small book or on sheets of paper.

All locks for a chemistry laboratory should be made of brass in all their parts. All hinges on the door should be made of brass.

Table Shelving. Some do not care to have any shelving above the table tops. This is particularly true in the case of tables for physical chemistry. Most teachers prefer shelves, or rather a single shelf, about fourteen inches above the table top and running the full length of the table at the center. Such shelves serve a double purpose; they provide a receptacle for reagent bottles and other apparatus when in use, and also furnish a support for the water, gas, and other pipes carried to the table. A convenient arrangement is to have the shelf about eleven inches wide with a division at the center. Such shelves are usually made of wood and finished with the acid-aniline stain. In the case of tables with soapstone tops the shelves are sometimes made of soapstone. These have the advantage that they do not burn when a burner accidentally gets beneath them.

With wall tables it is customary to put in two or three shelves, the lower one being about the height of fourteen inches above the table and the others about ten inches or a foot above the one next below. The upper shelf is often made much wider than the others to support large bottles or flasks. The objection to more than one shelf above the room tables is that they obstruct the view of the laboratory and are rarely necessary. In the case of wall tables in a special laboratory or a research laboratory, a number of shelves may prove very convenient. Being against the wall, there is no obstruction of view and they supply a handy place to have apparatus.

Arrangement of Piping. Cold water and gas pipes are usually carried under the shelves on the table tops. Sometimes they are carried under the table tops and brought through where used, but this method is not now so commonly used. Hot water and steam also are sometimes carried under the shelves. Electric conduits are commonly carried under the table top and brought to outlets just below the table top at the front. Sometimes they are carried along the shelving and the outlets are on the front of the shelves. Waste pipes from the sinks on the table tops are carried either under the middle of the table top to one end or to both ends in very long tables. The tables should be so built that access may be had to these drain pipes when necessary.

In the case of end sinks it is a common practice to carry the waste outlets through the floor directly under the sinks and the arrangement for bringing them together is made on the ceiling of the room below. As has been suggested in the case of tables with the sinks on the table tops a convenient method of giving access to the trap at the sink and the pipes in the immediate region is to have a cupboard opposite the sink and this cupboard is made with a removable or hinged back. Usually the cupboard and drawer parts may be moved out when serious trouble occurs with the waste or other plumbing carried there.

CHAPTER VIII

PLUMBING

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General. Two highly specialized problems confront the prospective builder of a chemical laboratory; first, ventilation; second, plumbing. Approximately 20% of the total cost of a laboratory will be required to provide for these two items including heating, and the installation and connections of the plumbing on the laboratory equipment, and if heat is to be generated in the building, 25% should be allowed. The cost of plumbing, including radiators and connections, is usually somewhat greater than the cost of ventilation; that is, 12 to 15% of the total cost of the laboratory. The chemist will receive less help from engineers and architects in connection with plumbing problems than with other portions of the construction work. While some plumbing fixtures can be standard articles, several types of special fixtures and outlets are required. Very few manufacturers or jobbers are in a position to furnish these special fixtures, and no one manufacturer is prepared to satisfy all of the diverse needs of the modern laboratory.

Supply Systems. Number of Commodities. The first decision the laboratory builder must make is with respect to the number of commodities or utilities to be provided in a laboratory. Water, cold and hot; gas; compressed air of two or more pressures; vacuum; steam of two or more pressures; hydrogen sulfide; distilled water; and oxygen should be considered in planning a building. In addition to the lines designated for definite utilities, some chemists provide one or more extra unassigned lines for future use. In this portion of this chapter we will discuss first, the source of each utility; next, the distributing

system—materials and location; and third, outlets—kinds, number, and location.

The Sources of Commodities

Cold Water. A central or municipal water supply is so universally available that the question of gravity storage or pressure systems need not be discussed here. The size of mains and meters should be passed upon by the chemist, by advising the engineer the amount of water required per student in each laboratory, and its pressure. In general, a 1¼-in. supply pipe will provide adequate pressure for fifty ordinary student workers; 2-in. for 100; and 3-in. for from 300 to 500. In order to meet special demands and supply industrial or research workers, additional provision should be made. Pressures of from 80 to 100 pounds per square inch should be maintained throughout a building where water aspirators are used. It is desirable to install a pressure regulator on the main supply line, and to make provision in ordinary faucets for restricting the rather violent flow which may be obtained with 100 pounds pressure. It should be pointed out that after supply lines of ample dimensions have been provided, the municipality or central supply company may install an undersized meter which will limit the quantity supplied at times of peak load. It is well to have T's and crosses on the supply main so that additional meters can be installed and the supply by-passed around a meter in case of emergency stoppage. Efficient traps for the removal of foreign substances should be provided on the main supply line. The mains in the building, through which all the water must pass, should preferably be of brass, although the outside mains are generally of cast iron.

Hot Water. Where hot water is distributed generally throughout a building, a generous storage tank should be provided. Where heat is being constantly applied, a tank holding five gallons for each worker has been found satisfactory in some institutions. A heavy steel storage tank, containing closed coils through which pressure steam is passed, is a very acceptable method of heating water. Special heaters, burning coal, have been used in the past, and for smaller installations instantaneous or thermostatically-controlled gas heaters may be used. If the

demand for hot water is intermittent, a gravity circulating system will prevent waste. In practically all parts of the country, it is considered essential to use brass pipe and fixtures for all hot water lines. Furthermore, it is highly desirable to have storage tanks of copper or brass. Since steam is considered an essential utility and is widely distributed in most laboratories, hot water is frequently prepared where needed from cold water and steam by mixers, which will be described under outlets.

Gas. Regular city gas is available in the vicinity of most laboratories. Connecting mains and meters of ample size are practically the only points to need the attention of the builder. A quantity of from 10-20 cu. ft. per hour should be provided for each worker, and additional quantities for boilers, water-heaters, and hot plates. Where municipal gas is not available, gasoline gas machines have been found to supply an acceptable substitute, provided, either a booster pump be used or the piping, owing to the low pressure, be made nearly twice as large as for ordinary gas. These machines require little attention, and the volatile gasoline required for charging these machines is readily obtainable in all parts of the country. Various companies supply compressed, liquefied, volatile, hydrocarbon fuels of high calorific value, such as Blau gas. When properly installed and a sufficient number of extra cylinders are available, this type of service is satisfactory. Special construction or adjustment of burners is usually necessary when using these less common fuels. Gasoline or compressed hydrocarbon fuel is preferable to acetylene for laboratory use. Gasoline torches are useful for small laboratories, and alcohol lamps may still be found in a few places.

Compressed Air. A number of rotary compressors, which in most cases are modified vacuum pumps and may be arranged to furnish slightly compressed air and a moderate vacuum at the same time, are available. These are especially recommended for small laboratories. Reciprocating pumps, such as are used in temperature regulating systems, have been found acceptable in some laboratories. Compressor outfits, designed for trolley cars, have also been used with some success. For large laboratories, commercial, reciprocating air compressors with belt or silent chain drive are preferable to rotary compressors. A wider range of pressures is then obtainable with a smaller consumption of power. Due to the varying demands for compressed air in a

laboratory, it is economical to have considerable storage capacity at relatively high pressure with appropriate reducing valves for the general distributing system where pressures of from 3 to 10 pounds per sq. in. are usually maintained. For special furnaces and compressed air motors, air can be withdrawn from the high pressure storage. Automatic electrical control of motor compressor outfits is generally installed, thus avoiding waste of power and variation in pressure. In some recent laboratories where compressed air is required, a compressor of suitable size is placed on that floor where laboratories require air pressure, thus eliminating the large installation in the basement with its highly expensive piping leading to the different floors. In research and private laboratories small compressors are mounted in a cabinet. These can be purchased at low cost, due to their high production for automobile tire work. This plan decreases the line losses of pressure as there are fewer leaks and consequently less waste of power. The compressors may be located in a sound-deadening room, and since the piping usually carries some noise, it is advisable to make a gap in the metal pipe with a heavy rubber tube bridging this gap.

Vacuum. In industrial and research laboratories, where there is a continuous demand for a partial vacuum, a central system with supply pipes to work tables may be considered, but in general chemical work, such as filtrations and vacuum distillations, simple water aspirators, either permanently attached or removable at will, supplemented by small portable motor driven pumps, seem to be preferred in most laboratories. With a general vacuum system, the accidental introduction of a relatively small amount of a volatile liquid or corrosive solid interferes seriously with all vacuum work for a considerable period of time. It is very difficult to provide the power equipment necessary to maintain a vacuum at the required standard under all possible requirements.

Steam. In spite of the increasing use of electrical heating devices, steam remains indispensable for a number of laboratory operations. Its special fitness for evaporation of water solutions both as regards constancy and degree of temperature, the absence of fire risk, and the almost universal availability of the commodity, are some of the factors involved. For general laboratory use, pressures of from 5 to 10 pounds are sufficient. For closed

coil and metal jacket heating from 15 to 40 pounds are usually desirable, and for certain purposes from 50 to 100 pounds are required. High pressure steam is usually supplied from a central power house, and the lower pressures are then obtained by means of reducing valves. The central steam supply system is frequently inoperative during the summer months, and it is increasingly common to supplement the outside supply with automatically controlled gas or oil-fired boilers within the laboratory. These are available in different sizes and are dependable in control if a fairly constant amount of steam is used.

Hydrogen Sulfide. The preparation and distribution of this objectionable but indispensable gas constitutes a difficult problem. With the exception of the generation of acetylene, probably no simple chemical device has been so frequently the focus of inventive attention. The Parsons generator and its host of near-relatives have apparently more adherents than any other device. This type of generator combines a moderate storage capacity with reasonably automatic operation. Oil-sealed gas holders are finding increased use in larger laboratories, and wherever general distributing systems are installed these gas holders are strongly recommended. They may be filled from intermittently-operated stoneware generators using iron sulfide and sulfuric acid, or from tanks of compressed and liquefied gas. This last-mentioned convenient source of hydrogen sulfide is now successfully employed in a number of laboratories. The compressed gas has the advantage of being free from moisture, which is the chief cause of corrosion and stoppage of distributing pipes.

Distilled Water. It is desirable to produce this indispensable material in a fairly uncontaminated atmosphere and in the upper part of the building, so that gravity distribution to various laboratories can be employed. Water stills, heated by gas, oil, steam or electricity, are available. The two last-mentioned types are especially commended on account of the quality of water produced and the possibility of utilizing automatic control. As is the case with other materials supplied to laboratory workers, the unavoidably wide variations in amounts used makes it desirable to have ample storage capacity; one gallon for each worker having been found sufficient for ordinary laboratory work. With storage tanks, smaller stills can be used and more

efficient operation secured. Irrespective of the source of heat, a water still should not froth, boil, or spatter over into the condenser. Volatile impurities should be vented so as to avoid contact with cold, condensed water; the water supply should be preheated, continuous, and the level in the still should not fluctuate: non-volatile impurities should be flushed out frequently, and all parts of the still and storage system, coming into contact with the condensed water, should be of pure tin or an equally insoluble material. Stills, combining these desirable features, are available. For small installations, gas-heated stills are commonly used. Electrically-heated stills are also very convenient, although uneconomical for large installations. As is the case with any type of evaporation, steam is the most generally satisfactory method of heating a water still. Steam pressures of from 30-60 pounds are usually employed, although somewhat lower pressures may be utilized. In the writer's laboratory, an automatically controlled, five-gallon-per-hour capacity, steam-heated still, combined with a 200-gallon storage tank, has supplied ample distilled water of good quality to more than 100 workers, and has required practically no attention for long periods of time. Many simple devices for condensing steam from general supply lines or from simple copper tin-plate stills have been suggested, but for a dependable supply of good distilled water, the purchase of a pure tin outfit is recommended, both for condensation and storage.

Oxygen. The increasing use of refractory glass and quartz makes the use of oxygen indispensable for glass working. It is also required in combustion and gas analysis rooms, and desirable for the operation of high temperature furnaces. The distribution of oxygen through a portion of a laboratory may, therefore, be advantageous. Cylinders of highly compressed gas are the almost universal source of this substance, and water-sealed storage tanks or gas holders are commonly used to retain it at the few pounds pressure employed in distributing systems.

Supplementary Gas Systems. The optimistically provident laboratory builder may consider the installation of unassigned gas storage and distributing systems. Such systems may be used for inert gas—nitrogen or carbon dioxide, or even the increasingly useful argon and helium—but before an appreciable outlay is made for such systems, the advantages of the use of

portable cylinders of compressed gases should be considered. With the wide variety of compressed gases now available at reasonable cost, it would seem to be more efficient and convenient to provide for occasional needs in this way rather than by elaborate distributing systems.

Distributing Systems

General Location and Arrangement. The general arrangement of supply lines for various laboratory utilities depends upon the location and arrangement of laboratory rooms. It is of such importance, however, that it should be kept in mind in making floor plans, assigning rooms, and locating work tables. In some buildings, the simplification and shortening of supply lines has been effected by placing work laboratories over one another in one part of the building, and grouping class rooms, libraries, and offices similarly in another part. The guiding principles in coordinating plumbing and floor plans should be accessibility of plumbing, short supply lines, absence of dead ends, and adequate size of lines. The chemist and the architect will probably differ on the question of exposed or concealed piping. The chemist should be willing to accede to the architect's demand for unobstructed ceilings and walls in corridors, libraries, and class rooms, but in laboratory workrooms the architect should recognize that exposed piping, properly arranged, is in keeping with the character of the building and that it avoids delays and expense in the detection and repair of unavoidable leaks. Some of the arrangements which satisfy both parties are vertical pipe wells at two or more places in the building where main supply lines may pass from basement to attic. These wells should be of sufficient size to allow workmen to pass up and down on ladders and make use of proper tools. Mains should be distributed around the well to provide ready access. For smaller pipes, wall chases or recesses, covered the entire length by readily removable panels, may be an advisable concession on the part of the chemist, but the size and location should not interfere with accessibility. To save space which can be used for wall and case work, these panels are, if possible, placed on the corridor walls.

Location, Arrangement, and Control of Horizontal Piping. Horizontal supply lines are sometimes placed in the upper part

of corridors and a false ceiling placed below, thus providing enclosed space a few feet in height, through which workmen can pass to make inspection and repairs, but such an arrangement has not been found very satisfactory. False ceilings and panel-enclosed ceiling recesses, similar to the wall chases referred to above, are also sometimes employed for horizontal lines, but this arrangement is more commonly made in offices and class rooms. Owing to the fact that horizontal supply and drain lines are more subject to corrosion and stoppage than vertical lines, a relatively small proportion of such supply lines should be so concealed in chemical laboratories. Supply lines, whether for liquids or gases, should be arranged to allow either continuous circulation or drainage. Loop supply lines, extending entirely around a building or a section, provide very successfully for circulation, and a pitch of ¼ in. or ⅛ in. to a foot toward the vertical supply with clean-out plugs, valves, or vents at the ends of lines, serve for drainage. Traps or pockets of any kind should be avoided in horizontal lines. Valves should be installed on mains and branch lines so that repairs can be made with a minimum amount of interruption. Steam and hot water supply lines should be kept away from cold water pipes as well as from electric wiring. The same relative position of mains, risers, and branch lines should be maintained throughout a building. Pipes, passing through floors or walls, should be enclosed in sleeves. Floor sleeves should extend a short distance above the floor surface to prevent liquids from passing through the openings.

Location and Arrangement of Lines to and on Tables. Branch supply lines for work tables are conveniently suspended on the ceiling below, whence they pass upward and then under or over work tables. An alternative arrangement places the supply lines on the outside walls of a room with branch lines leading to tables, which, in this case, must extend to the walls. The third and least desirable arrangement shows the pipes extending downward to tables from overhead supply lines. This location of supply lines is frequently resorted to in basements, but for this floor it is also possible to carry supply lines in floor trenches covered by masonry or iron slabs. Difference of opinion exists regarding the location of branch lines on work tables. A substantial majority of chemists place these lines above the working top where they are accessible. No branches are required for individual out-

lets, and support and space are naturally provided by reagent shelves. Other chemists prefer to have the desk tops as free as possible from reagent shelves and supply lines, and these lines are, therefore, carried under the work tables behind the cabinet work. When combined with readily removable unit systems of cabinet work, this location may be satisfactory, but in the opinion of the writer the disadvantages outweigh the advantages.

Distinctive and Protective Paints. Special coverings and protection of individual supply lines will be discussed under the different commodities, but, in general, it is desirable to thermally insulate lines carrying any substance which differs appreciably in temperature from that of the surrounding air. General identification systems of painting piping have not been so much employed in chemical laboratories as in manufacturing plants. The standard colors of red for fire protection equipment, yellow for dangerous materials, green and achromatic colors for safe materials have been little observed. When colors are used practices differ; in some cases the colors chosen are not at all in accord with standard colors; in other cases only fittings or wall sleeves are marked, and it is more common in laboratories to make use of distinguishing colors or markings on or near outlets. Special pipe covering paints are marketed by certain paint manufacturers, and these serve acceptably, although they have no special advantages over any good, lead-free, metal paint. The well known black iron-paints—asphaltum paints—may be used if black is desired. Increasing use is being made of aluminum paints or bronzing dispersed in lacquer solvents, but more acceptably in spar varnish. Lacquers, especially those of the most recently developed types, may be used where organic solvents, caustic solutions, and wide variations in temperature are not expected. However, an increasing number of chemists recommend aluminum powder and spar varnish paint as being in general the best suited for laboratory pipes.

Cold Water. Cold water distributing lines which are accessible may be of generous-sized, wrought iron pipe with ½ in. branches for each faucet. While conditions vary widely—owing to differences in the hardness of water—after a few years' service, iron pipe is likely to become partly closed with scale, and should, therefore, be from 25-50% larger than the calculated requirements. Pitting and rust also decrease the effective life of iron pipe.

Furthermore, if one takes into consideration the large proportion of labor cost in plumbing work in most localities, it may be found that it is ultimately cheaper as well as more satisfactory to employ nominally permanent materials such as brass, copper, or lead, preferably brass. In most laboratories, water pipes are given a coating of protecting paint, but it is also desirable to cover such pipes with standard asbestos or felt insulation, or with a layer of ground cork paint. When such coverings are used, surface condensation is prevented and colder water obtained for chemical uses.

Fire Control. Additional items of equipment that may logically be discussed under the heading of water supply are fire control systems which are found in a number of modern laboratories in unpacking and storage rooms, and in emergency showers which should be placed in all general laboratories so that they are readily accessible and will respond instantly.

Hot Water. Hot water is usually distributed in brass pipe, and for laboratory construction this practice is strongly recommended. Hot water pipes should be thoroughly insulated and loop lines with continuous circulation used where appreciable quantities of water are in demand.

Gas. Ordinary wrought iron pipe is satisfactory for gas distributing systems. Pockets, or traps in piping should be avoided. Gas lines should be carefully tested for leaks before acceptance from the plumbing contractor. Small leaks, concealed by cabinet work of tables and in similar inaccessible places adjacent to laboratory workers, should be especially guarded against.

Air and Vacuum. Ordinary wrought iron pipe is used for distributing compressed air. It should be pointed out, however, that such lines should be carefully tested for leaks before being put into service. Such testing may be done with a gas of strong odor or by the length of time a definite pressure can be maintained in the distributing system of a laboratory. The same type of pipe and the same precautions in testing should be observed in the installation of vacuum lines.

Steam. Extra heavy wrought iron pipe is recommended for steam, although it is common to install ordinary iron pipe. Provision should be made for expansion of steam lines by means of loops, swing joints, or in short lines by fastening at one end only and making provision for movement of the remainder of the line.

Steam pipes should be thoroughly insulated, magnesia coverings being most commonly used, but where steam pipes are on work tables and therefore likely to be injured mechanically, asbestos cell covering will shatter and dust less. All steam lines should be trapped and a return provided.

Hydrogen Sulfide. Some chemists insist that only the most chemically resistant materials should be used for the distribution of this gas; a solid glass pipe line being in their estimation almost ideal. This insistence is justified if water in any form is introduced with hydrogen sulfide into distributing lines. Hard rubber cocks and aluminum pipe have been tried and in a number of cases lead-lined iron pipe or lead pipe has been used. Some investigations of such systems indicate little advantage in the use of these special materials. If the hydrogen sulfide is relatively dry and pure, and extra-heavy wrought iron pipe is used, with no straight run longer than can be conveniently cleaned out with a rod, with cross fittings at frequent intervals to permit such cleaning and with care in establishing a regular pitch in the pipes so that any liquids will run either to the outlet or be returned to the generator, an economical and satisfactory system can be obtained.

Distilled Water. No satisfactory substitute for block tin pipe has apparently been found for the distribution of distilled water. It is well to have the composition of the tin pipe used checked by means of careful chemical or spectrum analysis. It is also necessary to inspect closely the material used to close joints in tin pipe. It is safest to insist that the plumber use for this purpose only pieces of the original lot of tested pipe. The so-called pure tin solders, examined by the writer, all contained lead. Owing to its elasticity, vertical lines of block tin pipe should be supported at frequent intervals, and horizontal lines should be carried in some sort of rigid support. An aluminum painted angle iron trough is a convenient horizontal support, as it allows for inspection and repair of the tin pipe. In some laboratories, tin pipe has been led through iron pipe, but this is objectionable because leaks cannot be readily discovered, and repairs are more difficult to make. Some use has been made of tin-lined iron, brass, or copper pipe, but in the opinion of most chemists, this type of pipe is not so satisfactory as block tin for distilled water. As implied above, joints in tin pipe have to be made by a process of burning rather than soldering, and the operation is simplified

if one end is constricted and the other reamed out so that only a small opening remains to be closed with melted tin. Traps and air pockets should be avoided in distilled water lines, and one or two especially designed control valves should be placed on main lines leading from water storage tanks.

Oxygen. Lines for special gases are usually constructed of extra heavy wrought iron, and should be rigorously tested for leaks, as loss of special gases is a more serious matter than is the case with air.

Outlets

General Types of Table Cocks. The type of small cock to be used for tubing connections in chemical laboratories will depend somewhat on the location of the supply lines. Where lines are above the table and back of the ordinary working space, cocks can be placed directly on the supply pipes with "T" fittings. The appearance of this portion of laboratory plumbing is improved if smooth, beadless fittings are used. Cocks for the purpose just indicated are most commonly of brass with small lever handles—the so-called "butterfly" handles are less desirable. Laboratory cocks of this general design are marketed by several plumbing supply houses and by makers of laboratory furniture. They differ considerably in weight and design of hose-connecting nipple. The cheaper cocks, with light weight handles and cock seats, are less durable and more likely to develop leaks. Hose-connecting nipples are usually corrugated with back sloping or acute-angle serrations. Long tapers assure firm attachment of different sized rubber tubing. Connecting nipples without corrugations have been successfully used in some laboratories, but the use of a definite size of tubing and a careful proportion of taper is necessary. The nature of the utility to be secured from a given outlet may be indicated by stamping, or better by indefaceably casting a letter or a name into the handle of the cocks, or by painting the outlet or the adjoining fixture and pipe a distinguishing color. The position of an outlet or its supply pipe and the employment of different designs of handles for each different commodity are valuable aids in preventing confusion of fluids.

Special Outlets. If supply pipes are below the table top,

branch lines and elbows are usually installed so that the type of cock previously discussed can be installed just above the surface of the table. In hoods, on lecture tables, and over regular working tables, ordinary cocks or small valves may be placed just under the table top back of the working space and bent nipples for hose connections brought up through the top. Special fittings for this purpose are available from at least one supply house. Control of cocks so located is established by means of rods which extend the stem of the valve or cock to beyond the front of the table. The usual type of cock may be located at the front of the cabinet work of the table with hose-connection nipples pointing upward so that tubing can be laid over the front edge of the table through holes in the surface or behind a protecting bar to apparatus on the top of the table.

Finish of Plumbing Fixtures. The finish of laboratory outlets is a matter of special interest. The common finishes for domestic fixtures—nickel and lacquer—while frequently used for laboratory fixtures, soon assume an unsightly, irregular appearance. Chromium-plated cocks have been tested by the writer, and for many purposes are an improvement over nickel-plating, but in hoods or where contact is had with chlorine or hydrogen chloride, they are equally unsatisfactory. It is hoped that stainless steel fittings may become available in the near future, for they would seem to have many desirable properties. In some laboratories, a surface coating of black asphaltum enamel or aluminum bronzing is applied to cocks and refinished when necessary. In others, ordinary brass or bronze outlets are used without protecting coating and the natural black of copper sulfide and oxide allowed to develop to a more or less uniform coating. Some chemists accelerate this natural darkening of copper alloys by surface treatments recommended for producing a black finish. Since laboratory fittings and hardware naturally assume dark colors, it would seem to be reasonable, and it is feasible, to blacken all fittings and hardware to be used in a chemical laboratory.

Water Outlets Over Sinks. On account of cheapness and simplicity, ordinary bib water faucets are commonly used where supply lines are conveniently located above sinks. Furthermore, supply pipes may be formed into loops over sinks and thus provide support for this type of water outlet. Gooseneck faucets,

which are somewhat more convenient, are also very frequently used for water outlets over sinks. As previously mentioned, it is desirable to maintain a relatively high pressure in laboratory water lines to insure the proper operation of aspirators. For this reason, slow-opening valves or some means of reducing the force of the stream of water from an ordinary gooseneck is desirable. One way in which this can be accomplished is by replacing the ordinary butterfly handle with a lever, thus decreasing the amount of angular movement which is naturally made when one opens a cock. Another method is to restrict the flow from the supply pipe by using constricted or partly closed nipples. Such nipples can be prepared by the simple procedure of placing the nipple around a steel nail, filling the nipple with molten lead and withdrawing the nail. Special cocks are also available which have internal adjustments to control the flow. Faucets should be so designed that a smooth, non-splashing stream of water is delivered, and the height of the outlet should be sufficient to allow the largest apparatus used to be placed conveniently under the faucet. A distance of from 16 in. to 20 in. above the rim of the sink is acceptable for most work. In each laboratory it is desirable to have at least one faucet at a distance of from 2 ft. to 3 ft. from the sink, so that large apparatus as well as burettes and long tubes can be conveniently washed. Special foot-control fixtures and faucets, with levers that can be operated with the elbow or back of the hand, are recommended for certain laboratories, especially those in which biological or sanitary work is carried on. In store rooms, inverted, needle-stream, gooseneck faucets are convenient for rinsing or washing bottles and flasks.

Water Outlets Over Tables. Small water cocks for hose connections are generally the stopcock type with lever or butterfly handles. There are, however, two objections to this type of cock. Unless unusual care is taken in lubricating such cocks, leaks generally develop, and, furthermore, it is difficult to adjust the flow of water to the slow stream usually desired. These objections are avoided by using small compression faucets with hose connection nipples, or the writer has found it satisfactory to use an enclosed needle-valve cock with packed stem which was designed for use as a gas cock.

Aspirators—Suction Pumps. Aspirators are usually placed over sinks or table troughs so that the suction tube extends

toward the working space just above the table top. Water is best supplied by a small compression cock, and the aspirator so placed that the stream of water is directed against the side of the sink or trough, thus preventing spattering. The same result can be secured by placing a short piece of rubber tubing on the lower end of the aspirator. In a number of laboratories, it has been found to be economical and convenient to thread the outlet end of small water cocks or faucets so that hose connecting nipples or aspirators may be used interchangeably.

Hot Water. If hot water is distributed generally throughout a laboratory, it is most conveniently used in mixing faucets so that its temperature can be controlled. As has been indicated under the discussion of the production of hot water, steam-cold-water mixers are being used in several new laboratories. There are several types of mixers on the market which are reasonably acceptable, but if this method of securing hot water is contemplated and commercial mixers are to be used, samples of the various devices should be tested. The writer has found it satisfactory to employ an ordinary brass, water aspirator or filter pump for this purpose, connecting the steam supply to the side tube of the aspirator after the inside diameter of this tube has been enlarged to about ⅛ in. With steam at 10 lbs., a medium or large sized aspirator, costing a small fraction of the price of a commercial mixer, yields a gallon of water per minute at a temperature of from 70 degrees to 80 degrees C. The device operates quietly and the temperature of the hot water can be varied at will.

Gas, Air, Vacuum, and Oxygen. Lever stopcocks of good weight with long taper hose connections are the most satisfactory for the delivery of these commodities. When simple type Bunsen burners, without provision for the regulation of gas and air at the base of the burner, are used, some chemists prefer needle-valve gas cocks or the type referred to above under water outlets. The height of the outlets above the working table and the direction in which the hose connection extends should be so fixed that it is convenient to attach rubber tubing, and kinks will not be caused in flexible tubing.

Steam. Ordinary stopcocks and needle-valves with metal seats, not designed for use with steam, are not recommended for outlets delivering this commodity. Small, slow-opening steam

cocks are generally considered most satisfactory. To these hose-connecting nipples can be attached. Thermal insulation on steam lines should extend to the valve fitting, and long branch lines, incapable of drainage, should be avoided.

Hydrogen Sulfide. Metal cocks are generally considered to be unsatisfactory for hydrogen sulfide. Difficulties of attaching and fragile nature are objections to glass cocks. Small, hard-rubber cocks with hose-connection nipple on one end and standard pipe thread on the other have been used with apparent satisfaction in several laboratories. It is desirable to prevent too rapid flow of hydrogen sulfide by means of some device installed in or preferably beyond the controlling stopcock. Short pieces of thermometer tubing used to connect stopcock and delivery tube, is one of the most common devices. In the writer's laboratory, it has been found very satisfactory to fill a short piece of ordinary glass tubing with molten Carnauba wax and allow this to solidify slowly in the air. The contraction of the wax produces a series of small pores or cracks which allow an appropriately slow diffusion of hydrogen sulfide through the tube when it is inserted in rubber connecting tubing in the usual way. More rapid flow of gas can be produced by perforating the wax with a fine iron wire. The passage of gas through the wax is not as readily stopped by dust as with capillary tubing or porous porcelain, and warming and cooling is all that is necessary to restore the original porosity if the wax is accidentally stopped.

Distilled Water. Distilled water outlets should be located over sinks or catch basins to prevent unsightly spattering. Self-closing cocks, described as tin-lined, are almost universally used. An examination of all the makes of this type of cock that the writer could secure, indicated that other metals than tin were or would be in contact with the water after the cock had been in service a short time. However, if the first water to flow from a cock is rejected, negligible amounts of metal are dissolved during the subsequent passage of water through the cock. The writer experiences natural resentment when using a self-closing cock, and has installed simple, lever, bib stopcocks thoroughly coated with tin. These deliver water so rapidly that there is no occasion for a worker to remove his hand from the cock while filling any ordinary container. While these have been in use for only a relatively short period, no waste of water has been noticed as a

result of lack of self-closing devices, and the tin surface has remained unbroken. For the control of the distilled water supply at the storage tank or for cut-off valves in the main distributing system, especially designed gate valves, entirely coated with tin, are available, but they are too expensive for use at ordinary outlets.

Laboratory Waste Drainage Systems

General. These systems consist of sinks, troughs, drainage cups, and all similar means of collecting liquid chemical waste, and the necessary drainage pipes to discharge these wastes outside the building. Sanitary drainage systems in laboratories do not differ from those in other buildings and will not be discussed here, but it should be pointed out that sanitary drainage should be collected separately from chemical waste. Devices designed to collect liquid chemical waste are frequently called upon to receive solid waste as well, but such waste is usually disposed of either by using stoneware vessels on tables or under sinks, or by earthenware or resistant metal strainers and baskets placed upon or over sinks.

Location of Waste Pipes. The location of sinks has been discussed in Chapter VII and, as pointed out, is usually at the end of or between working tables. Parenthetically, it may be noted that it is desirable to have at least one sink or drainage cup under a hood in each room so that objectionable vapors, emitted by waste materials, can be discharged. Other waste receivers may be troughs, which extend through the middle of a double table, draining into sinks at the ends or in the center of the table. Small acid cups or merely open T's and L's in wrought iron pipe, may be substituted for troughs as receivers for waste from apparatus such as condensers. The usual position of these waste receivers indicates that the natural location of chemical drainage pipes will be along the center line of tables below the working surface. All that has been written in the first part of this chapter, regarding the necessity for accessibility of supply lines, applies with increased importance to waste lines. It is undesirable to place drain pipes behind cabinet work; it is better to suspend them from the ceiling below. All drainage lines should be of ample size, supported at frequent intervals, with sufficient pitch to provide gravity flow and with no low

places where pockets of liquids can be retained. Clean-outs should be placed at all bends and at the end of long straight runs. The ends of all lines should be vented and sufficient traps of chemically resistant materials installed to prevent the escape of objectionable gases. Floor drains should be installed in all laboratories. It is desirable to install a small vented cistern of chemically-resistant materials on the main drainage line where it leaves the laboratory, so that mercury and small heavy objects may be recovered and a certain amount of dilution of strong acids effected before discharge into municipal or private sewage systems. In the remainder of this section, we shall first discuss materials and dimensions of waste collecting devices; and second, drainage lines.

Waste Collecting Systems. Three materials of sufficient chemical resistance to be classified as nominally permanent in character have been employed in chemical waste systems, and justify serious consideration by laboratory builders. These are —first, chemical stoneware; second, soapstone, and third, chemical or silicon cast iron, such as Duriron. Slate has been used for sinks in a few installations, but while cheaper in cost than other recommended materials, it is generally considered to be unsatisfactory for chemical purposes because of lower resistance to mechanical shock, thermal change, and chemical corrosion. Lead-lined sinks are resistant to certain chemical waste, but for general hard usage are not considered desirable, although lead-lined troughs have been found satisfactory. Monel metal is well adapted to use in hospitals, but is not sufficiently resistant to the action of strong acids to be used for chemical laboratory sinks. Sinks and other waste receivers are also available in porcelain and enameled iron, but these materials are somewhat too soluble and sensitive to temperature changes and discoloration to be given serious consideration in laboratories.

Stoneware Sinks. Chemical stoneware sinks have recently been widely used. The body of this material is chemically-resistant, and the surface glaze renders it entirely impervious and easy to clean. Corners are rounded so that solids can be readily removed, and, being formed in one piece, no leaks develop at joints. Dark brown stoneware is most commonly used, and is apparently obtainable with more uniformity of shape and color than stoneware of lighter color. Traps and outlets are formed

integral with the sink, and splash backs can be secured when desired. Some chemists object to chemical stoneware because of the lack of regularity in size, which causes difficulties when fitting sinks under desk tops and into the cabinet work of tables. This objection is sufficiently well-founded to justify consideration and to necessitate careful specification and inspection of stoneware apparatus, with the privilege of rejecting any pieces not found to be satisfactory.

Fig. 44. Laboratory Table Showing Waste Receivers and Sinks.

Soapstone. Soapstone sinks are also extensively employed. They can be secured in exact sizes, joints are now very carefully made and seldom give trouble, and outlets and traps of the same material are furnished which are satisfactory. Drain boards, shelves, and strainers of soapstone, joined permanently to the sink, are available, and installations of this material are pleasing in appearance. Table troughs are most commonly formed of soapstone. The plain surface, secured with this material, makes it possible to secure complete drainage and to fit troughs to sinks and table tops with precision.

Silicon Iron Sinks. Silicon cast iron has been less used for sinks than stoneware or soapstone chiefly on account of greater cost, but for special acid receptacles and sinks subjected to wide variations in temperature it is recommended.

Location of Sinks. Sinks should be located close to the working space of each individual. A center trough, while convenient for receiving clean water waste from hose connections, cannot be considered a satisfactory substitute for a sink. In general, it is cheaper and more satisfactory to provide a generous-sized sink for the cooperative use of several workers than a small one for each worker. The sink should be placed so that it is unnecessary to reach over more than a few inches of desk top to use it. Most workers prefer to have the sink somewhat lower than the top of a work table. The design and inside dimensions of sinks should aid in preventing spattering and yet be large enough to allow ordinary apparatus to be filled and emptied with convenience. A minimum average for a number of laboratories indicates a height of 8 in., a depth of 18 in., and a width of 16 in. for an individual sink. The adoption of two or three standard sizes for the entire laboratory makes for economy.

Drainage System Materials. Chemical stoneware and cast iron—both ordinary and silicon iron, such as Duriron—are worthy of serious consideration when choosing materials for drain pipes. Lead, lead-lined iron, hard rubber, and special fiber composition pipes may serve acceptably for conveying definite and oftentimes very corrosive liquids, but they are not as satisfactory as the materials first mentioned for general laboratory use.

Chemical Stoneware Drains. Ordinary vapor-glazed, brown, chemical stoneware, identical with the material used for sinks, is available in the form of hubbed drain pipe, and a number of new laboratories are employing this materials. The body of this ware is chemically resistant and practically impervious, and is further protected by a continuous salt or dip glaze. Owing to deformation, due to shrinkage on firing, it is especially important to have rigid specifications regarding the dimensions and shape of stoneware pipe and to reject all lengths not reasonably round and straight. When properly selected, little objection can be made to the appearance and permanence of individual pieces of stoneware pipe. The chief objection to this material

arises from the difficulty of securing entirely satisfactory joints on horizontal lines. The chemically resistant preparations used for joints are difficult for ordinary workmen to use and are softened by steam and hot water as well as by some organic liquids, and do not adhere well to smooth glazed pipe. If, however, both the inside of hubs and the outside of pipe ends which are to be joined are formed with numerous, small, circular corrugations, these difficulties can be overcome. If chemical stoneware drainage lines are satisfactorily installed and maintained for a period of several months of actual service, and if large volumes of hot water, steam, and high concentrations of organic liquids are not carried through such lines, this type of installation is generally considered to be the most satisfactory available, but it must be anticipated that the repair of a leaky joint in such lines is a more delicate and expensive operation than the replacement of a section of cast iron soil pipe.

Iron Waste Pipe. Silicon iron pipe is considerably more expensive than stoneware and is somewhat more fragile than cast iron, but it is easier to install than stoneware and requires little expense for upkeep. It is especially recommended for use where hot, strongly-corrosive liquids are to be handled. Ordinary cast iron is recommended because of its cheapness and the ease with which a reasonably satisfactory installation can be secured. It is to be expected that corrosion will necessitate replacement with accompanying interference in the use of the laboratory, but the cheaper first cost and the practical consideration of the greater familiarity of workmen with this type of material are points in favor of this material. For ordinary laboratory installations, where small concentrations of acids are found in the waste, it may be satisfactory. If ordinary cast iron drainage lines are used, elbows, running traps, catch basins, and main traps should be of silicon iron.

Miscellaneous Plumbing Equipment

Toilet Rooms. Inspection of modern laboratories suggests that one toilet room should be provided for each group of 100 students. In buildings having an area of 15,000 sq. ft. or more on each floor, at least one toilet room is found on each floor. Research and industrial laboratories, whose occupants spend all

of their time in one building, are frequently equipped with one toilet room for each fifty workers. Toilet room floors should be so constructed that they can be easily flushed to a floor drain,

Fig. 45. Steam Baths, Mallinckrodt Laboratory, Harvard University.

and all partitions or walls should be washable and capable of being easily refinished or restored to the original surface. Simple, durable fixtures of modern design in white porcelain are appropriate in a laboratory building. If sanitary drinking fountains are not placed in convenient locations throughout a laboratory they may be placed in or near toilet rooms. Steel lockers, which can be assigned to workers who are using poisonous or vesicant chemicals, are, with one or two shower baths, a necessity for such work, and this equipment is a great convenience in any laboratory. Coat hooks, sanitary dispensers of solid or liquid soap, and paper towel holders complete the usual equipment.

Steam Baths. Steam baths are an essential part of laboratory plumbing. Fixed installations are usually made in hoods. A common type of steam bath consists of a soapstone box, lined with copper, with circular openings, flush with the floor of a hood. Water is maintained at a constant level in the box and heated by closed, steam coils, or by direct injections of steam into the water. Copper, monel metal, and silicon cast irons are sometimes substituted for soapstone in the construction of the bath. Copper, monel metal, asbestos wood, or porcelain concentric rings are fitted to the circular openings. Soapstone or monel metal troughs, approximately 6 in. deep and 6 in. high, fitted with constant level water supply with outlet to a drain, and heated by steam directly or through coils, may be arranged in vertical banks against a wall with provision for rapid removal of air over each trough. Individual baths are convenient in organic laboratories, and usually consist of non-rusting metal funnels 8-10 in. in diameter at the top, fitted with concentric rings, and with facilities for admitting steam at one side and withdrawing condensed water at the bottom. Portable steam baths of cast iron with asbestos wood concentric rings or combined steam-water bath and pneumatic trough devices of copper or other metal have been used successfully.

Hot Plates. Steam hot plates of bronze or heavy cast iron, and steam coil heated shot baths have been installed in some laboratories as a substitute for live steam baths, but are more expensive and less efficient. Drying ovens, heated by steam coils or steam jackets are conveniently placed under hoods and are especially useful in quantitative laboratories.

Glass Laundry. The cleaning of glassware, especially that used in organic laboratories, is a disagreeable and time-consuming operation, and some laboratories have installed what might be called a glass laundry. The first step in the cleaning operation is the treatment of glassware with cleaning solution, concentrated sulfuric acid and chromates or nitric acid, and this mixture is conveniently heated in a steam-jacketed Duriron kettle. A heavy wire basket of nickel-chromium alloy is a convenient means of immersing and removing glassware from the acid bath. The succeeding steps in the cleaning process vary in different institutions, but it is convenient to have a large sink of warm water for rinsing, special distilled water outlets for final rinsing, and portable drain racks or trucks which can be placed in drying closets through which dry, clean, warm air is passed.

CHAPTER IX

ELECTRICAL EQUIPMENT

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The increasing use of electrical equipment is one of the most notable developments in laboratory installations. The obvious advantages of electrical heat, light, and power are well understood by chemists and by makers of laboratory apparatus. The permanent equipment of a laboratory, therefore, must include ample supply and distributing systems for present needs and should also provide for future extension and additions.

Sources of Alternating Current. Alternating current is now almost universally available from public utility corporations at voltages of 110 and 220, and, if necessary, at higher voltages up to that of the high tension lines of the distributing company. If an outside source of electric current is not available, dependable light and power systems, driven by gasoline engines, are available at relatively low cost. Small, automatically-controlled outfits, designed for house use, may serve for small laboratories.

Sources of Direct Current. Direct current is less commonly available from outside sources, and usually is generated in a laboratory. If this type of current can be secured from a central power station, it offers advantages for use with small motors, such as variable speed and quiet operation. Direct current is, of course, essential for electro-chemical work, and a dependable source is, therefore, indispensable for any laboratory worthy of the name.

For occasional, short time use, where constancy of voltage is not essential, primary cells, commonly dry batteries, may supply direct current. Small generators, connected to alternating current motors, may be employed for intermittent use where it is not necessary to have constant voltage. The voltage of the direct current produced by such generator outfits can usu-

ally be varied by adjustments on the generator or by means of outside resistance. This same type of generating system can readily be secured in large units, and is the most common primary source of direct current if a capacity of more than a few amperes is desired. The wide demand for low-voltage direct-current for radio reception has rendered available a large number of rectifiers which may serve as the primary source of direct current, if only small current strength is desired. For such small capacity installations, these so-called battery chargers are available with tube and vacuum bulb devices which require little attention and have a long life. For medium capacities, the mercury arc rectifier, formerly used, has been largely replaced by bulb rectifiers of the Tungar type, and these serve acceptably for direct connection to circuits as well as for battery charging.

Storage Batteries. In order to produce the constant electromotive force necessary for quantitative electrochemical experiments, storage batteries or accumulators are necessary. Lead-sulfuric acid accumulators are the most common, but Edison nickel-iron alkali cells, although somewhat more expensive, are also used. Accumulators should be supported on acid-resistant frames and shelves, with trays under each cell to collect electrolyte accidentally spilled. Heavy lead connections are generally used to join individual cells. It is desirable to set aside a separate room for storage batteries and arrange for thorough ventilation of this room, especially during times when charging current is being applied to the batteries. All batteries should be protected by fuses or circuit breakers. Battery rooms should have a floor drain, a shelf or bench for the repair or filling of batteries, and a convenient supply of distilled water for replacing evaporated electrolyte. A jar or bucket of sand is convenient to use in absorbing electrolyte that is accidentally spilled. In addition to a fixed installation of storage cells, it is convenient to have portable battery outfits of voltages of from two to twelve. These should be stored in the battery room when not in use, and kept fully charged at all times.

Combination Outfits. Motor generator outfits, previously referred to, are the most dependable source of current for charging battery installations. Such outfits can also be used alone or by appropriate connections in conjunction with a set of batteries.

Small battery sets may be charged by means of rectifiers of the radio type, and it is also convenient to install one of these rectifiers to supplement a motor generator when only a few cells of a set have been run down by use. Storage cells of widely varying capacities are available, and as many units as are necessary to produce the desired voltage may be installed. It is generally considered advisable to have sufficient cells to furnish 110 volts with a few extra cells for replacements. Large laboratories frequently have 220 volt cell systems with variable voltage generators, capable of producing a current of 250 volts. In any installation, the generator potential should be somewhat in excess of that of the storage battery system. It is advisable to place a reverse current circuit breaker between batteries and generator to prevent the discharge of batteries through the generator if the motor of the outfit should unexpectedly cease to function. Measuring instruments of different capacities and ranges should be attached to the switch board, as well as variable resistances capable of regulating outgoing current.

Current Distribution

Conduits. Wiring for various laboratory circuits is generally carried in rigid metal conduits. The builder should insist that these conduits be of ample size so that wires can be readily drawn through them. Somewhat larger sized conduits than those specified in standard engineering guides are recommended. Extra, unassigned conduits, paralleling regular conduits leading from supply boards to laboratories and offices, should be installed when a building is erected. Conduits should be smooth, free from moisture or foreign matter, and enameled or thoroughly rust-proofed both inside and out. Conduit-carrying, experimental circuits should be exposed to allow for inspection and provide for future replacements and enlargements. Frequent, readily accessible junction boxes, panel cabinets, etc. should be provided. Outlet boxes should be of sufficient size to allow receptacles to be removed or repaired without disturbing supply circuits. Standard electrical equipment of all types is strongly recommended. Black enamel, iron pipe conduits with cast iron outlet boxes or condulet fittings are commonly used. Special designs of conduit connections which allow easy replacement of sections of conduit, special short radius

elbows, aluminum fittings, and aluminum pipe conduits are especially advantageous for laboratory installations. Conduits and electric outlets should not be placed below water pipes nor fixtures, nor close to steam pipes. They should be free from traps where water or other liquids may collect.

Exposed Wiring. Some chemists prefer to employ exposed wiring on laboratory work tables on account of the greater ease of making new connections. Various types of wood and metal moldings are available for supporting such wiring. Flexible conduit is sometimes substituted for rigid iron pipe conduit, and is especially advantageous for use when a laboratory is being reconstructed, as it is difficult to establish connections to main circuits through rigid conduit. In the opinion of electrical engineers, however, these types of electric distributing systems are not to be recommended for chemical laboratory use.

Switches and Fuses. For experimental circuits, whether A. C. or D. C., knife switches are preferred by most chemists, although some snap switches insure positive contact. Circuits should be adequately protected by fuses or circuit breakers between the source of current and the distributing system, and in addition it is sometimes desirable to have fuses near the outlet. Both 110 and 220 volt alternating currents are useful in laboratory work, and with three or four wire distributing systems it is possible to provide both voltages at the same point.

Distributing Switch-Boards. In order to provide flexibility in the use of storage battery systems, it is convenient to connect each cell or group to carefully designed and constructed plug receptacles. Laboratory circuits are similarly connected to plug receptacles, and connection established between source and circuit by means of flexible cords attached at each end to plugs which fit the receptacles. For small laboratories, one plug receptacle switch-board with connections to each separate experimental circuit may be sufficient, but for larger laboratories, several small plug and receptacle panels may be placed at different locations throughout the building and connected to the main switch-board by feeders which can be plugged to the desired supply. On the smaller panel boards, distribution can be effected by means of flexible cords as previously described. Various methods of connecting receptacles to batteries and charging equipment may be devised so that charging and discharging

equipment may go on without changing connections, and a variable number of cells may be included in the circuit by means of only two connecting cords on the face of the board. Compact battery generator and switch-board outfits in one cabinet are manufactured ready for installation. On switch-boards, circuits should be permanently labeled with circuit numbers and polarity. Cells should be numbered and connections correspondingly marked. Blue prints of wiring systems should be readily available for tracing circuits and determining capacities.

Multi-Wire Distributing Systems. In large installations it is desirable to provide and distribute direct current from generators and use portable cell outfits in rooms where lower voltage is required. It is convenient to have two or more low voltage generators which, when connected in series, will give 110 volts and, in some cases, 220 volts. By means of three or more wire distributing systems, separate low voltages as well as the combined voltage can be made available throughout the laboratory.

Outlets

Alternating Current. The most convenient outlet for alternating current is a standard T-slotted, 10 ampere capacity receptacle mounted on the standard outlet box, since most portable electrical devices are provided with plugs which fit such receptacles. Standard outlet boxes permit the mounting of a considerable variety of outlets, but specially designed equipment is not recommended as it is difficult to replace if changes are necessary after the original installation. If more than 10 amperes is to be continuously withdrawn from an outlet, larger capacity receptacles and plugs should be provided, and supply wires for such outlets should be correspondingly increased in capacity. It is well to impress upon the electrical engineer the desirability of having main circuits of sufficient size to allow for from 50 to 100% over-load at the outlets originally installed; that is, each branch circuit to an individual outlet should have a minimum capacity of 20 amperes. The number of outlets provided should be generous, especially in laboratories where research work is to be carried on, one outlet for each 3 feet of desk front usually being sufficient. Provision should be made for additional circuits on switch-boards, and main supply lines should have a capacity in

excess of the total anticipated connected load of the system as originally installed.

Large Capacity Outlets. Special provision should be made at some point in the laboratory for the use of the maximum amount of current the supply system affords. Heavy cable connections from bus bars may be made to large capacity furnaces for high temperature work. Arc, induction, and resistance furnaces are necessary for many laboratory operations and large capacity outlets should not be overlooked in planning a laboratory, although furnaces of this type may not be in immediate demand when the plans for the laboratory are being made.

Position of Outlets. Outlets should be located above cocks and supply lines for ordinary laboratory commodities, if such lines are above the table tops. Receptacles are sometimes placed flush with the table top and connected to circuits carried through cabinet work of the desk. In general, this arrangement is objectionable, but if it is necessary, receptacles so placed should be protected from contact with water and other liquids which will undoubtedly be spilled upon table tops. Porcelain and chemically resistant composition receptacles should be used in preference to brass and other metals. Flush receptacles, placed on the front of the cabinet work of a desk, are less objectionable than those placed flush with the table top, but wiring connections are liable to be accidentally detached from receptacles in this position, and liquids may also find their way into the receptacles.

Direct Current Outlets. Polarity plugs and receptacles may be used as outlets for direct current for general use where the constancy of electromotive force is not important, but the more generally used direct current outlet consists of some form of screw contact distinctly marked with the polarity, designed to firmly attach loose single wires. Composition plates on standard outlet boxes or regular condulet fittings can be secured with two or more knurled-head, polarity-marked screws. Circuit numbers, corresponding to the numbers of the main or sub-panel switch-boards, enable the worker to secure the desired voltage from the central supply. If low voltage generator current is distributed, three or more polarity and voltage marked connections to permanent circuits, carrying definite voltages, may then be used to supply the varying needs.

Other Electrical Devices

It is beyond the scope of this chapter to attempt to describe the wide variety of electrical devices that may be considered part of the permanent electrical equipment of a modern laboratory, but it may be helpful to make brief mention of one or two devices which chemists in various laboratories have found useful.

Communication Systems. Intercommunicating telephone systems, electric clock and call bell outfits, as well as regular outside telephone systems are a great convenience and should be provided for in laboratories containing more than two or three rooms. Telephones should be restricted to rooms that are not open to the public except in cases where there is an attendant in charge all the time. Telephone pay-station booths may be installed in the corridors, if desired. Telautograph systems are used in connection with store room service in some laboratories. The chief provision that is necessary during the erection of a laboratory to make possible the immediate or ultimate installation of such devices is a sufficient number of conduits connecting rooms where the systems are likely to be needed.

Hot Plates. Nickel-chromium alloy resistance wire or ribbon, insulated and supported in various ways, is commonly used to construct hot plates flush with the floor of hoods or of table tops. These same alloys, insulated and encased in sheets of iron and monel metal, are also available in the form of strip heaters which can be conveniently attached to the under side of cast iron plates, supported on metal or asbestos wood frames and insulated by magnesia or similar material. Hot plates, complete with switches and connections designed for use in kitchen ranges, may be installed in non-combustible table tops. With proper selection of capacities and current, and spacing of heating units, wide variations in temperature can be secured, and evaporations and digestions carried out without the objectionable presence of waste steam and condensed water experienced when steam baths are used.

Drying Ovens. Drying ovens of asbestos wood or similar material may be permanently installed and at various places in a laboratory which would not ordinarily be used. These ovens may be heated with electrical resistance units or with steam

coils or jackets. Automatic temperature regulators can be connected with the circuit and a cheap and serviceable oven produced.

Water Baths. Water baths, heated by electric hot plates or preferably by immersion heaters, are very convenient, especially in small laboratories where steam is not always available. Large capacity immersion heaters, enclosed in monel metal sheets, may be used for heating large water stills as well as for a large variety of distillation and extraction equipment.

Vacuum Cleaners. In the wiring of the building, provision should be made both in the corridors and the various rooms for outlets to serve for vacuum cleaners. They should be flush with the base board and be covered with a flap to prevent the entrance of dust or water. A large capacity vacuum cleaner, permanently installed in the basement and connected to suction mains with convenient outlets at various parts of the building, should be given consideration by the builder of a chemical laboratory.

CHAPTER X

SERVICE AND STORAGE ROOMS

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Location. Prompt and efficient service is the primary consideration in the location of service and storage rooms. They should be easily accessible, near the laboratories they serve, and ample enough to furnish without delay all the ordinary needs of workers in the laboratories. In very large chemical buildings there may be several service rooms located conveniently to the working laboratories, and if possible, connected with the main stock room. In medium-sized structures, one service room on each floor will prove satisfactory, if located in a strategic position, while in smaller laboratories one general service room, properly located, will suffice. When service rooms are on each floor, it is advisable to have them arranged one above the other and over the main stock room with connecting stairways and elevators. These rooms should be well lighted, supplied abundantly with apparatus and chemicals. In some large institutions small service rooms are placed in direct connection with large laboratories or between two laboratories. This involves expense in manning a number of such rooms and has the defect that the rooms are usually small and much time is lost procuring materials from other service or store rooms. It is very convenient in serving quickly the ordinary things that are called for every day and its expense is a consideration in most laboratories. It resolves itself, however, into a question of the slight cost of a student attendant against the great inconvenience and loss of time caused by students having to run up and down stairs.

Elevators and Dumb-Waiters in Laboratories. Where small service rooms are used it is necessary to have dumb-waiters to bring goods from stock rooms as well as a large elevator somewhere near the service room. Where large service rooms are

planned there is but little call for the dumb-waiter and only the elevator is necessary, but even in this case a dumb-waiter is serviceable. It should be located near the serving window and should be automatic if possible. It is preferable to have the freight elevator open into the service rooms. Some elevators are made to open into both the service room and the corridor of each floor, and this is a convenient arrangement. An elevator should be large and strong with a platform of twenty-eight square feet or more. Here, too, it is better to have it electric and automatically-controlled from each floor. An elevator is needed even though it has to be pulled by hand with a rope. Where service rooms are located one above the other it is very convenient to have them connected by winding stairways; winding, because these take up a small amount of space. Ordinary stairways, where there is plenty of room, are still better. This arrangement saves much time over that of having to go to the general stairways of the building to pass from one service room to another.

Fig. 46. Store Room, University of Iowa.

Service Room Equipment. Perfection in service room equipment calls for great flexibility so that it can take care of old and

new apparatus and supplies. Therefore, there need be no highly specialized drawer and shelving arrangements expensively planned to take care of everything in one place. Cabinets and cases should be built on integral bases to permit of their being placed elsewhere in the store room or in other rooms should need require. The sizes of drawers, sacks, bins, or shelving will necessarily vary according to the size, needs, and numbers in different institutions, but laboratory equipment manufacturers now provide standard equipment of such varying dimensions and adjustable parts that every need may be met without special, and therefore costly, construction. Hence the sizes of equipment occasionally mentioned in this and other chapters are only suggestions of special items that should not be overlooked, or to enable the planner to provide space for their installation.

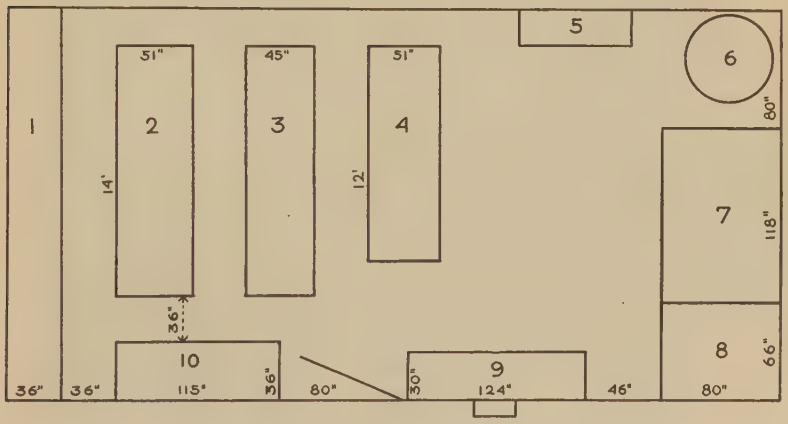

Fig. 47. Typical Stock Room.

1. A set of drawers below and shelving above to ceiling.
2. Drawers below and shelving above on left side; shelving from floor to ceiling on right side.
3. Shelving from floor to ceiling on left side, bins from floor to ceiling on right side.
4. Bins on one side, drawers and shelves on the other.
5. General Sink.
6. Winding stairways to other floors.
7. Vault.
8. Elevator.
9. Small drawers about service window, with shelving above.
10. Case with long drawers (72 in.) together with cross drawers at left end. Shelving above case.

The arrangement and dimensions are only suggested. These are taken from a room which is giving excellent service.

Interior Arrangement of Rooms. Figure 47 represents a typical arrangement of service rooms. An issuing window is to be located in the place where it will give the best service. Below and about this window should be located a large bank of drawers in which the server may have for immediate delivery a large number of the small articles used in the laboratory work, such

Fig. 48. Chemical and Apparatus Case.

as crucibles, stoppers, test tubes, small beakers, etc. A suitable size for these drawers is a case forty-four inches high by twenty-four inches deep and as wide as the location will permit. One hundred drawers are not too many for such a bank. Drawers three and a quarter inches high, eleven inches wide, and twenty inches deep, are a convenient size. Another bank of drawers about six feet long should be provided for the storing of glass tubing and other long articles such as condensers, glass rods, etc., and so placed that the drawers will pull out parallel to the

wall, though some prefer to have the receptacles for glass tubing left open at the ends so that the bore and thickness of wall may be seen at a glance.

Shelving and Drawers. Where the major part of the service room has built-up shelving for chemicals and various kinds

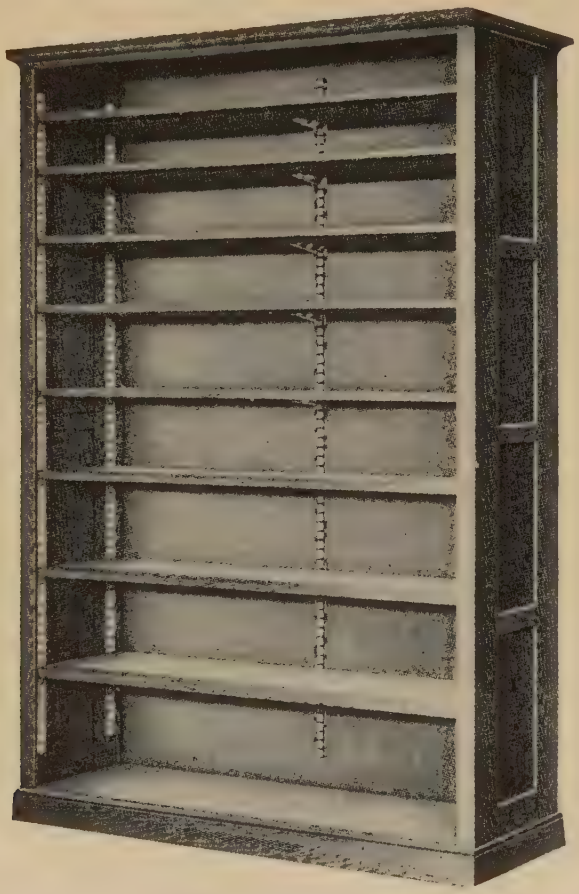

Fig. 49. Supply Shelves.

of apparatus, bins for glassware, ironware, and other goods, and large drawers for the bulkier stock of various kinds, a good arrangement is a bank of drawers from the floor to the height of forty-eight inches, and above this, shelving for chemicals and for apparatus. The large banks, as the drawers may number

hundreds in a moderate sized laboratory, may vary in size but they should be roomy. A satisfactory size is a bank forty-eight inches high and the individual drawers fifteen and a half inches wide, four and a quarter inches high, and thirty-three and a quarter inches deep. These are only suggested dimensions which have been found to work well. Some prefer that the lower drawers have greater height than the upper ones. One reason for having them all of the same dimensions is that they may be arranged under a single alphabet. When higher ones are used and shallow ones placed above them, it is impossible to use a single alphabet in regular order in arranging the materials in the drawers. However, it is possible to carry a single alphabet with an arrangement something like the method used in the case of shelving. These drawers ought to be so numerous that one is obliged to use the alphabet in locating the drawer contents. For this reason good, plain, large labels should be placed on the drawers. These banks may be placed below either bins or shelving. Some have made them much higher and have used ladders to reach the upper drawers, but this is not a convenient

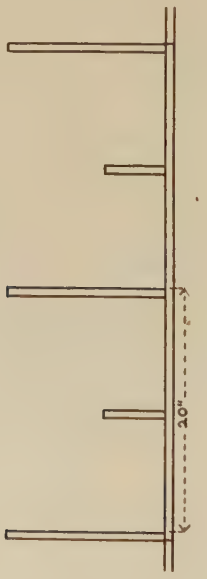

Fig. 50. Showing arrangement of shelving for stock room for the storage of chemicals. Small bottles are placed on the narrow shelf and larger ones on the wide shelf, the two shelves being carried together in the alphabet.

arrangement. The best arrangement is to have the banks of drawers extend no higher than will allow of easy handling while standing on the floor. By making the banks about forty-eight inches high, their top serves well as a table or shelf, particularly when they are below shelving. The bins may either extend out flush with the drawer banks or they may be somewhat recessed, giving a narrow shelf on the top. For storing chemicals much space may be saved by arranging the shelving in the form shown in Figure 50. With this arrangement a single alphabet may run on the two shelves—the tall bottles on the deeper shelf and the smaller bottles on the shallower shelf. Reagent shelving like this may either run from the floor to the ceiling or it may begin at the top of a bank of drawers.

Bins. Banks of bins may be arranged in the same way either beginning at the top of a bank of drawers or running from the floor to the ceiling. They are used for the storage of beakers, flasks, iron ware, wooden ware, and the many varieties of glassware. A common method is to arrange a movable front board closing only the lower part of the bin. The height of this front board will depend on the dimensions of the bin. In a larger bin it may cover more than half the height of the bin front, but in smaller bins it may cover less. The sizes of bins naturally vary with the institution. It is convenient, for example, in making beaker bins to have them at least large enough to hold at the same time more than one original case, so that the bin may be replenished by a full case before it has been entirely emptied.

Sometimes bins are entirely closed in front and become in reality small cupboards. The closing may be brought about by having the front upper half suspended by hinges on its upper side. Another plan is to have a door or doors hinged on the side in the usual fashion, but this arrangement still calls for the front board on the lower half of the front so that the contents of the bins may be retained. Closed bins have the very good feature that they keep the bin contents free from dust and exposure. Some make the bottoms of the bins of heavy meshed wire so that dust and dirt may not collect there. This arrangement gives circulation of air up through the bins and this may carry dust with it, so that the advantage of this form is not very great. Where the bins have movable fronts they are easily cleaned.

Aisles between cases of bins or stacks of shelves may be as narrow as thirty-six inches. Between cases of drawers they must be wide enough to permit the taking out of the drawers. These figures are given for minimum widths of aisles—they may be made as wide as desired where there is abundant space.

Movable Trays. A device which has found favor in some laboratories consists in arranging shelves which are quite deep and which will support movable trays or cases. Materials are stored in these movable cases and the whole case may be picked up and carried to any place where a number of the articles are to be used. For example, on a given day a large number of flasks may be needed at the issuing window. One of these trays which is filled with flasks may be taken from the large shelving and temporarily placed near the issuing window and when the rush is over, is replaced on the shelf. In such arrangements the shelf may be simply a suitable frame support and not a solid shelf. By making all of these trays of one standard size they may be interchanged at any time to suit the convenience of the users, or they may be made of two standard sizes, one being twice as wide as the other so that two smaller trays occupy the space of one large one. If it is desired to keep these free from dust, bins may be used which have closing doors in front but are without the movable board suggested for the regular bins. Another arrangement for these carrying trays is to make the bins like closets with doors several feet high and with a number of shelves in each closet.

While wood is the ordinary material for shelving, racks and bins, attention is called to the recently-introduced steel furniture for this purpose, and to the construction of shelves of asbestos wood with angle iron frames, both of which have the added advantage of being fireproof.

Working Table and Sink. Every service room should have a working table and a general sink. The working table should have an acid-aniline finished wood top or one made of soapstone. It need not be larger than three by five feet.

The general sink should be of good size, and should have a drain board at one or both sides. Cold water, hot water or steam, and distilled water should come to the sink, and gas and electricity to the working table. Above the sink it is well to have

a board of drying pins. If a glass laundry be installed, the needed equipment will be found described in Chapter VIII.

Movable Tables and Wagons. It is desirable that space be had in the service rooms for a movable table of good size. It is not best to have the whole room entirely filled with bins, shelves, and drawers. Every stock room should have some kitchen or similar wagons for the transportation of apparatus or chemicals in quantities. They have large rubber wheels and convenient carrying trays. Laboratory equipment companies now manufacture a series of movable tables specially designed for this service. Some of their wagons have a 1½ in. mesh screen top with a copper tank at the bottom. This meets all requirements for carrying materials and also provides a handy draining rack. Service rooms should be equipped with one or more of these, and the connections between rooms and corridors should be so made that these wagons function readily in going from one room to another.

Vault. Every laboratory should have at least one vault which is well constructed, has ample size, and is provided with regular bank vault doors. Every laboratory has platinum ware and other valuable materials which should be kept in such a vault. Some laboratories have a vault on each floor or for each subdivision of the subject, which is a very good arrangement. The interior of these vaults should have shelving with space for housing suitable cases. A vault in connection with the main service room is a very useful arrangement and probably pays for itself in the conservation of expensive materials. The floor space inside the vault should have at least thirty square feet of surface.

Ladders. If the shelving or bin stacks go up to the ceiling, necessitating a ladder, the present stock room practice is to provide a horizontal rail about ⅔ of the way up the side of the case or shelving. Portable ladders with a curved iron fit over this rail, and can be placed out of the way when not required to take material out of the cases. A simple ladder with wheels on the floor and a guide at the upper end with a small shelf at the top is a very suitable and inexpensive form. Many such ladders are on the market, as they are used in stores. Ladders which can be used only in one place or on one bank, should not be provided. To obviate the need of ladders one large institution has built its bins and cases in such a way that the lowest bin extends some

six inches beyond the next higher, and this in turn extends six inches beyond the next, and so on till the top of the bank of bins

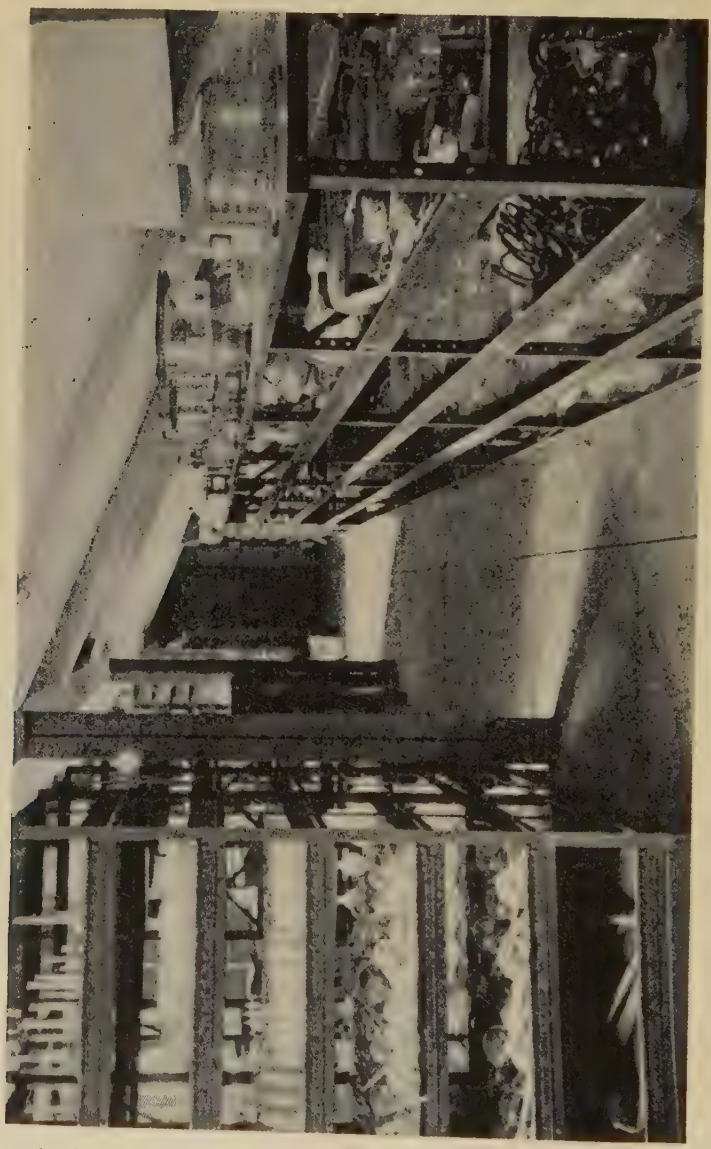

Fig. 51. Apparatus Supply Room, Wesleyan University.

is reached, where a man of average height can reach articles on the higher shelves.

Receiving and Unpacking Rooms. Closely connected with good service are rooms for the reception of supplies and their unpacking. A door of ample size should be provided in the basement at the rear of the building, or in an inner court through which drays may deliver goods in bulk to the unpacking room where they are to be opened, checked, and distributed to the stock or service room. This room should be made large enough to form part of the storage system by taking care of a quantity of boxes, such as stocks of glassware in original cases, which it is not desirable to open when first received. It should have a cement floor reinforced by iron plates at the point of unloading boxes, be electrically lighted, and may be provided with water and a small sink. Plenty of tables and shelving should be supplied to hold apparatus and chemicals while the unpacking is in progress, so that each shipment may be readily checked. The tables are especially helpful in getting the materials in good shape for removal to storage or service rooms. In larger unpacking rooms midroom shelving may be used in addition to the wall shelves. This should extend from floor to ceiling, the upper part being used for bulky materials or for temporary storage. Shelves may be made of plain materials, but should be strong. Fire hose, extinguishers, and, if possible, a sprinkler system, should be installed. Some provision, either in the shape of a small fireproof room with an iron door, or a covered metal receptacle, should be made for holding the packing materials and empty cases awaiting their disposal.

The store room, preferably adjacent to the receiving room, should be well lighted, sufficiently large to hold the needed supplies of the institution, and provided with ample bins, racks, and shelving. Some of the latter should be large enough to store original packages of glassware or porcelain. The elevator or dumb-waiters to the service rooms should originate in the main stock room or as near to it as possible. Fire protection furnished by sprinkler systems, fire hose and extinguishers may be augmented by the use of adjustable steel racks fitted with wire trays.

Acids and Special Stores. For the storage of acids and fuming chemicals, a special room should be provided in the basement, where strong acids may be diluted with water, and carboys emptied into smaller bottles. To avoid intermittent ventilation this room should not be vented into the general system, but

should have natural draft developed by a steam coil, placed below the vent to prevent corrosion. Sufficient heat, to prevent freezing in winter, should be supplied. The acid room should be furnished with rugged shelving (soapstone, slate, or asbestos wood may be used), spaced to carry the large acid bottles. Carboys should rest on raised concrete supports covered with some acid-proof paint. The concrete floor may be topped with any acid-resisting material, and should slope slightly to a drainage outlet. A faucet with a hose-end and a length of hose are useful for flushing floors where acid is spilled. A box of sand should be provided to soak up and stop the flow of acid from a broken bottle or carboy. Where any quantity of inflammable liquids like ether, benzine, alcohol, etc., are used, a special store room built of fire-resistant material and provided with an iron door and shutters, is desirable.

Junk Room. Many laboratories utilize for the storage of junk any waste space which they feel cannot be used for other purposes, though it is far better to have rooms, which are left unfinished. The main requirements for a junk room are space and shelving in convenient sets covering the entire side wall from floor to ceiling. These shelves may be made of ordinary materials, but should be rugged. Even small laboratories need a junk room, located in otherwise undesirable space. The throwing about of junk in an unfinished attic is not commendable, but attic space may be fitted for junk rooms where the materials stored will, at least, be kept in some order, and to some extent protected from dust and disturbance. Many a piece of half worn-out apparatus has been resurrected from a junk room and put to good use.

Shop. A properly equipped shop can be of great service as well as a financial asset to a laboratory, which is continually calling for the construction or repairs of apparatus. With proper tools and a place to use them, many a piece of apparatus, otherwise discarded, has been saved for efficient use without the expense and loss of time of sending it away for repairs.

A spacious, well-lighted room in the basement with mastic floor should be equipped with conduits and outlets so that electric power for small motors may be obtained in any part of the room. Lathes for metal and wood, a grinder and polisher, are the beginning of a shop equipment. These machines should be in-

stalled with individual motors. Space should be provided for cases and chests of tools and for storage of lumber and metals needed, as well as drawers for small hardware. A lavatory with hot and cold water or steam mixer is needed. It is possible to combine glass-blowing with the shop in a single room, since much of the repair work as well as construction is concerned with glassware, but a separate room is better.

Glass-Blowing Room. Both for instruction in glass-blowing and for the local construction and repair of glassware, a room should be provided large enough to hold the work tables required for the blowpipes, and the long racks or drawers for the storage of the varying lengths and bores of glass tubing and rods. Preference is shown by many for room tables, as they give more freedom of action in handling apparatus than do the wall tables. Whichever type is installed should be furnished with large gas and compressed air outlets conveniently located. The tops of these tables should be made of soapstone, asbestos wood, or tile, as they are exposed to high heat for long intervals. The ordinary wood table tops will prove satisfactory if asbestos pads are placed under and about the blowpipe. Space should also be provided for the storage of the various gas cylinders used with blowpipes. Where the laboratories for physics and chemistry are in the same or adjacent buildings the two sciences may readily combine and have a common glass-blowing room. This suggestion is made for institutions which do not feel able to provide such a room for chemistry alone.

Janitor's Room. Some institutions provide the janitor with a living room or rooms in the building. These should contain a toilet and lavatory as well as a shower bath. The rest of the equipment should be that of any good living room.

The janitor should have either a separate room for his implements or a number of closets scattered over the building, or preferably he should have both. About a building, spaces under stairways or in corners are to be found where closets may be located to take care of vacuum cleaners and other appliances used by the janitor. Each floor of a chemical building should have a closet, opening into the corridor, fitted with a janitor's sink and supplied with hot and cold water. There should be space enough about this sink closet to store the janitor's cleaning implements.

First-Aid Room. Should accidents occur which call for im-

mediate attention to the patient, it is desirable to have a "first-aid" room, with cabinets containing medical and surgical supplies needed for emergency treatment. (Serious cases call for a physician or surgeon and hospital treatment.) A lounge or bed, a table and some chairs, electric lights and fan, a lavatory and toilet constitute a suitable outfit.

Sometimes the rest rooms provided in connection with a toilet are used for this purpose, but a separate room is preferable, as it gives the patient freedom from disturbance by others passing through the room.

Rest Rooms. It is desirable to have rest rooms, adjacent to the toilets, with an entrance thereto. The furniture of an ordinary rest room will comprise lounges, tables, chairs, a mirror and decorations. A moderate-sized room will suffice, one for men and one for women,—in most laboratories. Where possible, separate rest rooms, lavatories and toilets should be provided for the teaching staff.

Post Office Room. In any building with four or five teachers it is convenient to have in the corridor or a room at least a set of boxes or small lockers which are used for the delivery and sending out of mail and inter-communication between teachers. In large chemical laboratories or in buildings in which more than one science is housed, it is very desirable to have a room which may serve as a post office for all teachers and helpers in the building, and a general center of communication as well as a source of such supplies as examination booklets, papers for tests, departmental stationery, etc. In smaller laboratories where the library is not large this room may be combined with the library office where one attendant may care for both. The special equipment called for will be a set of boxes of the usual post office type, and cases for supplies.

CHAPTER XI

LECTURE ROOMS, CLASS ROOMS, LIBRARY AND MUSEUM

J. N. Swan

Director, Department of Chemistry, University of Mississippi

Lecture Room. The seating capacity of a lecture room or class room is easily calculated by dividing the area of the floor space in square feet by ten, and this quotient will represent the seating capacity of the room. This number will probably crowd smaller class rooms, since the demonstration table will take up a greater percentage of the floor space than it will in a large room. However, this method of calculating will give a close approximation to the seating capacity when ordinary aisles are used and armchairs are installed and all the space is used for seats except that occupied by the lecture table and the aisles.

Size of Lecture Room. The size and seating capacity of the lecture room will depend primarily on the student registration for courses of Chemistry. According to the rule given above, to provide for two hundred students a room of about 50 feet by 40 feet, or slight variation of these dimensions, would be needed to give a good proportion between length and width. In some larger institutions, a seating capacity of 350 has been found practicable on one floor, and when a balcony is added, 500 students can be accommodated. By keeping the farthest seat within fifty-five feet of the lecture table, visibility of demonstrations and audibility of lectures will prove satisfactory.

Height of Ceiling. The ceiling height should be greater than that of a single story of the usual building. If it is convenient to give a height of two stories to a lecture room, not only will a

proper ceiling height be obtained, but a suitable slope of the floor may be had without getting too close to the ceiling. This would

Fig. 52. Lecture Room, Wesleyan University.

give twenty-four to twenty-six feet for ceiling height at the lecture table part of the room.

Slope of Floor. There are differences of opinion as to the proper slope of a lecture room floor. Some would have each

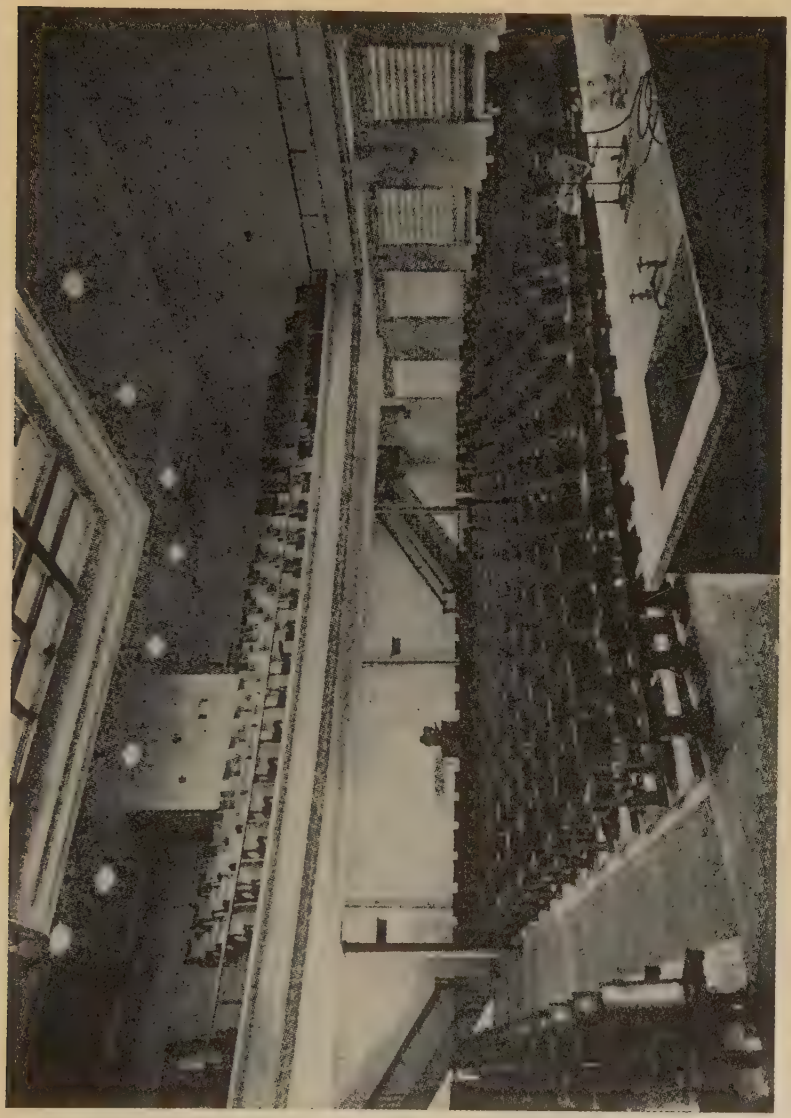

Fig. 53. Lecture Room with Balcony, Cornell University.

succeeding row of seats six inches higher than the one in front, while others would have this difference between the first and

second rows, but the next rise greater and so on to the rear of the room, where the difference between two rows may be as much as fifteen inches or more. In the case of a room with a seating capacity of not over two hundred, a regular change of five inches in height from one row to the next serves very well, as small a rise as four inches being used in some rooms. There is an advantage in having each step or the slope of the aisle uniform. If the difference in height is not more than five inches and thus conforms with the usual theatre slope, a ramp with a special surface to prevent slipping may be used, making it unnecessary to use steps. With extreme differences of level it is necessary to use steps in the aisles.

Seating. An ordinary chair with a fixed arm is about two feet wide, and comfortable rows of seats will be three feet from back to back,—in other words, a chair of this kind occupies a space of two by three feet or six square feet. Movable chairs may be used, in which case we need calculate only three feet for each row, and the chairs may be placed as far apart as desired at any particular time. In general, it is better to have the chairs fixed to the floor. For laboratory lecture rooms and classrooms, chairs with fixed writing arms are much in use, though in large classes, folding arms of special forms have proven advantageous. All the better manufacturers make standard chairs with strong, rugged arms for writing.

Location of Aisles. Aisles may be arranged to suit either the convenience of the planner or the users. A typical arrangement in a room which is forty-one feet inside width would be to place two aisles with four seats between the aisle and the wall. This would give a solid bank of chairs in the middle, nine seats wide. In general, it is best to avoid an aisle at the center. Figure 54 shows the arrangement suggested for this room forty-one feet wide. In the case of a room used as a classroom it is advisable to have aisles along the wall so that blackboards may be installed and used with the students standing in the aisles as they work at the boards.

Seat Numbers. Seats should always be numbered with large figures which may all be read from the lecture table. Figure 54 shows a method of arranging these numbers so that the "ones" are in a straight line front to back, the "twos" in a straight line,

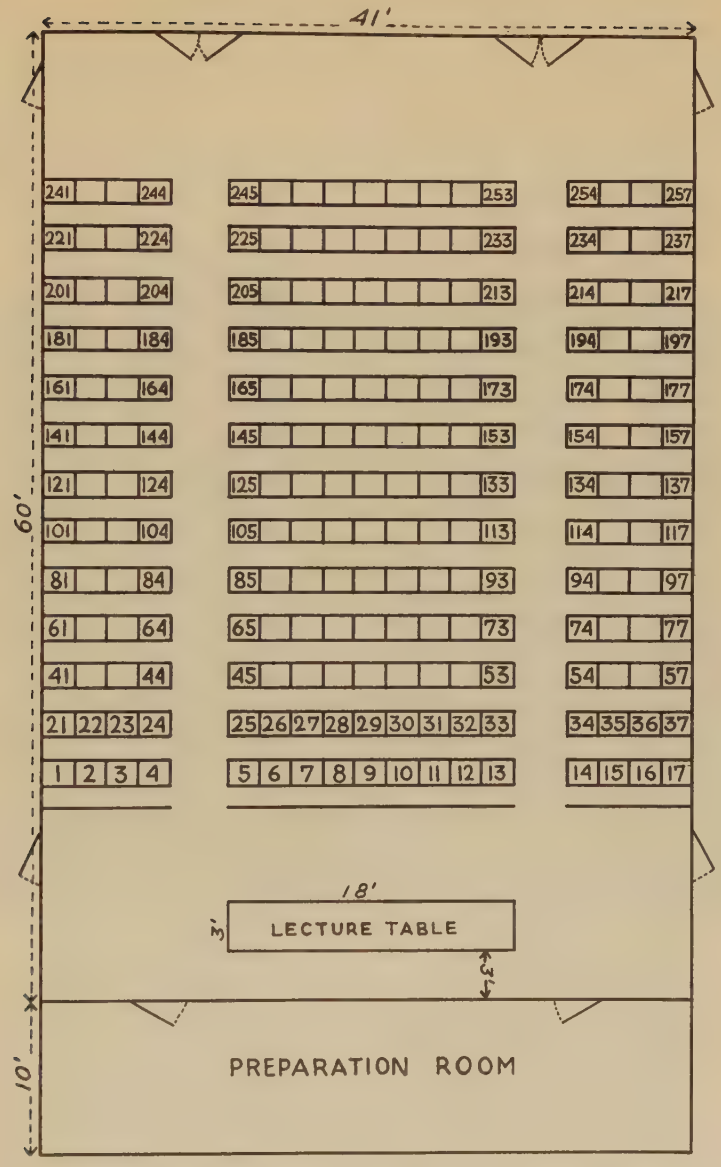

Fig. 54. Seating Arrangement in Lecture Room.

etc. In order to do this the numbers 18, 19, and 20 do not appear, likewise at the end of the next row the numbers 38, 39 and 40 are omitted. This arrangement gives the odd tens on the side of

the room at the lecturer's right and the even tens at his left. All of this makes a convenient arrangement, and the seats are extremely easy to locate. It does away with the calling of rolls if the students are assigned to seats.

Lecture Tables. As it is desirable to have plenty of space on the lecture table, a suitable size will be about three feet high, three feet wide, and for experimental lectures, as long as the room will properly accommodate, allowance being made for exits and

Fig. 55. Lecture Room and Table, Loyola College, Baltimore, Md.

the doors of the preparation room. The table usually has an acid-proof aniline wood or soapstone top, though white rubber or tile have been used in some recent laboratories. It is helpful to have the space below the rear centre of the table open to avoid interference with the speaker, and also provide a handy place for the temporary storage of apparatus which might be in the way on the top of the table. At the sides of this center space it is convenient to arrange two, three, or four banks of drawers, depending on the total length of the table. The rest of the space below may be taken up with cupboards and drawers if desired.

Equipment of Lecture Table. There should be a large sink at one end of the table, say twenty-four by eighteen by twelve inches. It is useful to have a large pneumatic trough near the other end, but some do not care for this, and use a sink in the top instead of at one end, which may be used as a pneumatic trough by closing a valve in the waste pipe. A suitable size for

Fig. 56. Lecture Room, Boston College.

a large pneumatic trough is the following: the top twenty-four by thirty inches, one half of the trough to be only four inches deep, that is, one half twenty-four by eighteen by four inches deep, the rest of the trough to be eighteen inches deep. Water, gas, air under pressure, electric currents, etc., are to be brought

to the table. Noxious gases may be led away by removable down draft hoods. Some tables are made with a waste pipe under the top and a few acid cups placed at intervals so that waste water from condensers or other apparatus may be conveniently carried away from all parts of the top. Some have been made with a shelf on front depressed below the level of the table top so that specimens may be there placed on exhibition without obstructing the view of the table top.

Tables with Movable Sections. In a few lecture rooms table sections have been mounted on wheels which run on tracks from the preparation room and usually are connected with the service systems of the central fixed table by couplings when the section is rolled into position. However, if the central table is made large enough and its service and waste outlets are plentiful, there will be no need of these connections. This enables a lecturer to prepare his experiments in a side room while another is using the lecture room. At the end of the hour the table used by the first lecturer is run out on the tracks and the incoming lecturer brings his table with him with all the experiments ready. Such an arrangement can be used only where there is room for a track on which the tables are run back and forth. These movable tables are not made so long as the fixed ones and are not so necessary if there are plenty of class and lecture rooms about the building. For this reason and because of the difficulty of getting suitable space to use them, such tables have not been very popular.

Blackboards. A large blackboard space should be provided back of the lecture table. In fact, the boards should cover all this space that is available and when fixed, should begin about three feet from the floor and extend upwards about four feet. In some laboratories, boards which can be raised or swing to one side are used. In others, only one board is suspended, and the other fixed in the usual way on the wall, in which case, the wall board should be of slate and the movable blackboard made of composition material. Slate is the best material for a blackboard, but owing to its weight and the additional backing it requires, it is not conveniently handled in swinging or portable blackboards, where the lighter composition board makes a fairly good substitute. All blackboards should have a chalk trough two or three inches wide, extending along the bottom. The movable

boards afford a convenient means of leaving data, drawings, etc., undisturbed for days, while transient work is being done on the fixed board, besides furnishing auxiliary space when this latter is not large enough for the work in hand.

Shelving. It is desirable to have one or more sets of shelves placed conveniently near the lecturer, which should follow the usual construction for room shelves. Part of the set or one whole set may be made for longer bottles.

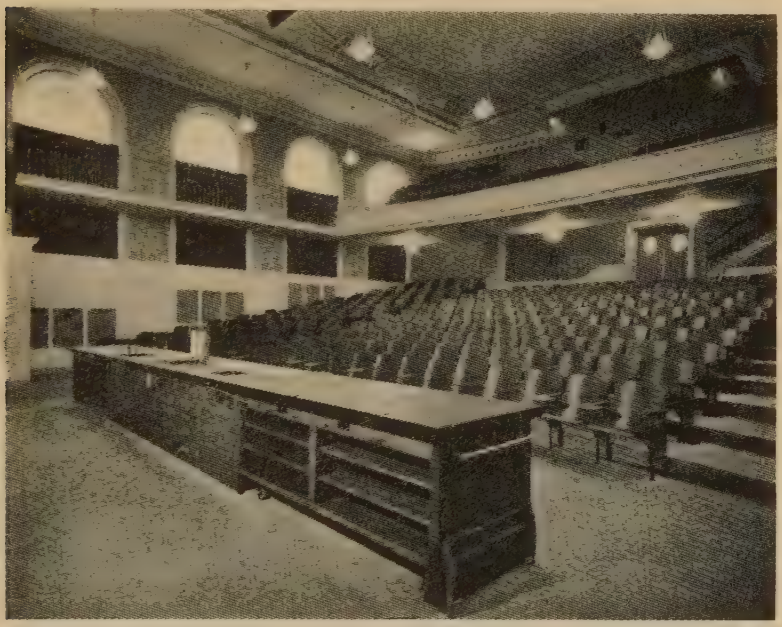

Fig. 57. Large Lecture Hall, Mallinckrodt Laboratory, Harvard University.

Lighting. The windows of the lecture room should have some arrangement for shutting out the light when projection apparatus is to be used. Several devices, electrical or mechanical, are in use for this purpose, and operate with either shades or shutters. A very simple device for class rooms is to have an extra frame set in front of the regular window frame with the opaque window shade placed between the two frames. As some rooms use only ceiling light, this is closed by shutters or a rolling shade which is controlled either by electricity or by a hand rope. The lights of the room should be controlled at the lecture table.

Projection Booth. Provision should be made for the projection of experiments, tables of data, etc., either on a screen which rolls up when not in use, or on a daylight screen, or on a section of the wall used for that purpose. Under proper arrangements, a projection booth may be installed at the back of the room and the screen used for films. It is evident that electric outlets of adequate capacity must be found wherever the projection apparatus is to be used. It is well to place a control of the lights of the room in the projection booth. The blank wall space above the blackboard may be used as a screen, or provision made through curtains.

Ceiling Supports. At times, it is very helpful to have some means of suspending charts or apparatus over the lecture table. It is desirable to have the supports to which these are to be attached quite strong. In the case of concrete ceilings this may be accomplished by suspending a beam on the ceiling over the table to carry devices to support apparatus.

Fig. 58. Preparation Room, Loyola College, Baltimore, Md.

Preparation Room. When movable tables are used for lectures, the preparation room must of necessity have considerable

size. The preparation room is a place in which experiments are prepared for the lecture demonstrations, and contains the apparatus and chemicals needed for this purpose. In some laboratories, compartments or closets are provided in which the individual teachers store the materials which they desire to use in the lecture demonstrations. These individual spaces may be like an ordinary cabinet with shelving and drawer cases. The teacher having one of these cabinets replaces his apparatus after

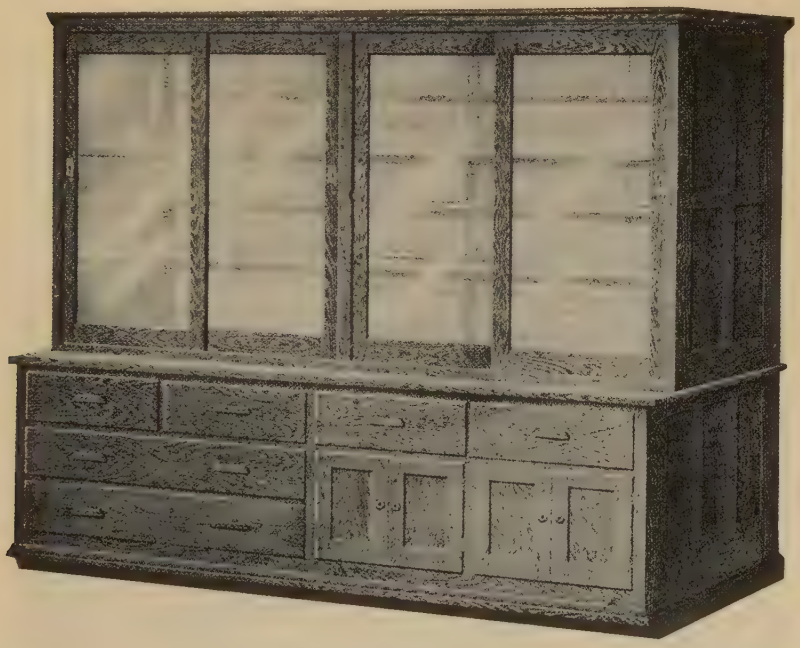

Fig. 59. Case for Apparatus and Supplies.

a lecture, and this is not disturbed by any other person. In other laboratories, there are general drawers, cabinets, shelving, cases, etc., and these are used by the different teachers in common. A preparation room is a very desirable adjunct to a lecture room. It need not be a large room, but it should be well equipped with tables, special apparatus, and convenient methods of getting materials out to the lecture room. Gas, electrical and water services should be installed.

Cabinets and Cases. Preparation rooms should be well

equipped with cabinets or cases for the storage of apparatus, which should be provided with sliding doors with glass panels to protect lecture appliances from dust and enable their contents to be seen at a glance. For display cases, both in lecture rooms and museums, plate glass shelves, properly supported, lessen the obstruction of light and present a neat appearance. Because of their general use these cabinets are carried in standard sizes by laboratory equipment organizations, and it is good policy to adopt certain standard sizes, as by their combination any reasonable requirements of space or materials may be met, and the cases may be interchanged about the building as occasion requires.

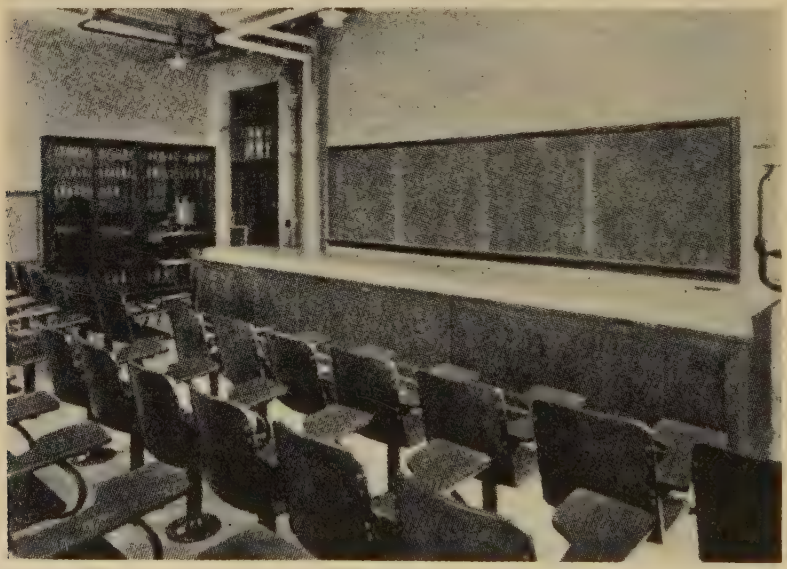

Fig. 60. Class Room, Wesleyan University.

Class Rooms. Class rooms are simply small lecture rooms. They are usually planned to hold from fifty to sixty (never more), and often hold not more than thirty, as an ordinary class or quiz section should not have more than thirty students. These rooms would call for relative dimensions a little greater than the regular sizes for seats in a lecture room, for example, to seat sixty students it would be better to have a little more than six hundred square feet of room, since it is desirable to have aisles

along the walls and to have these wide enough to use blackboards on both sides and the rear end of the room.

General Equipment. The general equipment of a class room should be the same as that of lecture rooms. If it is to be used for experimental lectures, the equipment of the table should not be so elaborate as that described under lecture rooms, but gas, water, drainage and electrical services should be installed.

Such rooms usually have exposure to outside light on only one side. The chairs should be so located that the windows are to the left of the students as they sit in the chairs. Arrangements should be made for darkening the windows when it is desired to use projection of any kind. This would call for electric outlets for the projection apparatus at the rear of the room and also on the side at the front where such projection apparatus might be used. Curtain or wall surface must be provided as a picture screen.

Library. Owing to the nature of the work carried on in chemical laboratories, it is desirable to have reference books and periodicals readily accessible. Even though the institution has only a small number of books and pamphlets on Chemistry when a new building is erected, provision should be made for a decided increase in the library. The same considerations must prevail in planning for a chemical library as in planning a general library, and ample provision must be made for the care and safety of the books and periodicals. Usually the library must be under the care and supervision of a librarian, for whom adequate equipment should be supplied. The library should be furnished with tables, book stacks, card catalogues and a desk. If space permits, it is desirable to have a separate stack room and an adjacent reading room, the latter containing general reference books and the current chemical periodicals. Provision should be made for expansion.

Location. In general, the library should be located in the quieter part of the building where the readers will not be disturbed; and also where it will be as free as possible from laboratory fumes which are destructive to the books and pamphlets. In carrying out the idea of quietness, it is well to have a floor which gives as little noise as possible. A linoleum-covered floor is excellent for this purpose, but mastic floors are quite satisfactory.

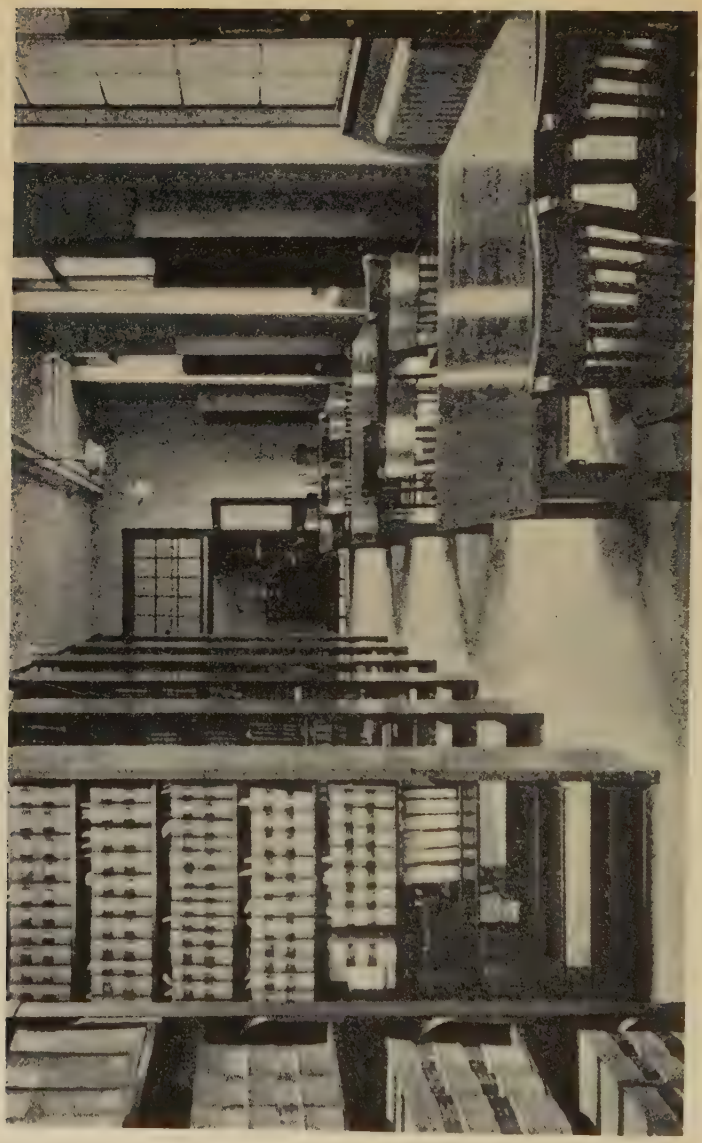

Fig. 61. Library and General Office, Wesleyan University.

For shelving, magazine racks, card catalogues and tables, there is no particular reason for departing from the standard equipments furnished by companies which manufacture these

library supplies. Since the library room should be remote from laboratory fumes, steel shelving may be used.

Museum. In modern laboratory buildings provision is usually made for the exhibition of museum specimens. Two plans are in use in carrying out this idea. One is to put such material in the wall cases which are placed in corridors, or on stairways, or in class rooms, and other rooms which are used for regular work and in which the museum cases are only non-essential additions. In some cases the main entrance corridor is very large and this is made into a museum room so that students must pass by the cases as they enter the building. In this way the students are brought in contact with this material whether or not they are making any effort to see it. This plan also does away with the necessity of having a museum room. The second method is to have a regular room or rooms devoted to museum exhibits. Some have used a combination of these methods, putting in the corridor or other cases these specimens which it is most desired that the students should see and using the museum rooms for special collections and those displays which are to be shown only to those who are looking for exhibits.

The principal objection to the corridor and entrance cases is that those who must pass them day after day show carelessness towards them and never stop to look at them. Often, too, it is difficult to preserve these cases in good condition. Being in public places or passageways, they are subject to more disturbances than are cases in a room devoted to the purpose.

The kinds of materials exhibited in chemical museum cases are as varied as those in ordinary museums, and therefore call for various types of cases. Some may be wall cases of little depth much like great enclosed bulletin boards. Mid-room cases of the flat type are suitable for the display of ores, crystals, and like substances, while perpendicular cases with shelves lend themselves to exhibits of materials which must be kept in bottles and jars. Most laboratories have specimens of old-time apparatus which are well worth preserving and exhibiting in suitable cases. Many industrial establishments are willing to put on display their products, together with illustrations of the processes used in their manufacture. Altogether a great variety of materials may be used in the make-up of a chemical laboratory museum. No uniform type of display cases or even a number of

types of display cases can be given with suitable dimensions—these must suit the collections to be displayed. There is no question, however, that it is advisable to make provision for a museum.

CHAPTER XII

OFFICES AND PRIVATE LABORATORIES

J. N. Swan

Director, Department of Chemistry, University of Mississippi

In larger laboratories the offices of the heads of sub-divisions should be in separate rooms, while in smaller laboratories one such office for the head of the department may be sufficient. These offices need not vary from ordinary offices either in shape, size, or appointments. An ordinary and satisfactory size is two hundred square feet of floor space but this may be made greater for some offices in larger laboratories.

Office Equipment. Such offices should contain the ordinary office equipment,—desk, book cases, filing cases, wardrobe, a closet with storage room, chairs, typewriter desk, etc. The office of the head of the department should contain a large number of filing cases. With larger offices a large table for varied work is desirable in addition to the desks. These office equipments are not peculiar to a chemical laboratory and may be selected, according to the personal desires of those using them, from stocks of office equipment usually available. It is desirable that the office of the head of the department shall have adjoining it an entrance office to be occupied by a secretary or stenographer. This room also need only follow the plans of such rooms in ordinary business offices both as to size and equipment. Telephone service and a lavatory should be installed.

It may not be amiss to stress here that wardrobe cases of wood or steel are replacing the old type of closets, as they are more economical, relieve building complications, conserve room space, and present a clean-cut appearance in the office rooms. It is now possible to select a standardized wardrobe in several

designs which may also be combined with a storage closet or case with adjustable shelves for general storage, or book case sections having glass doors, or a drawer section to meet various requirements.

Combined Office and Private Laboratory. Most of the offices may be a combination of office and private laboratory. A room with about two hundred square feet of floor space is fitted up with a regular working table along one side of the room. This table is equipped with three or more shelves on the wall above the table after the usual style of wall tables and with drawers

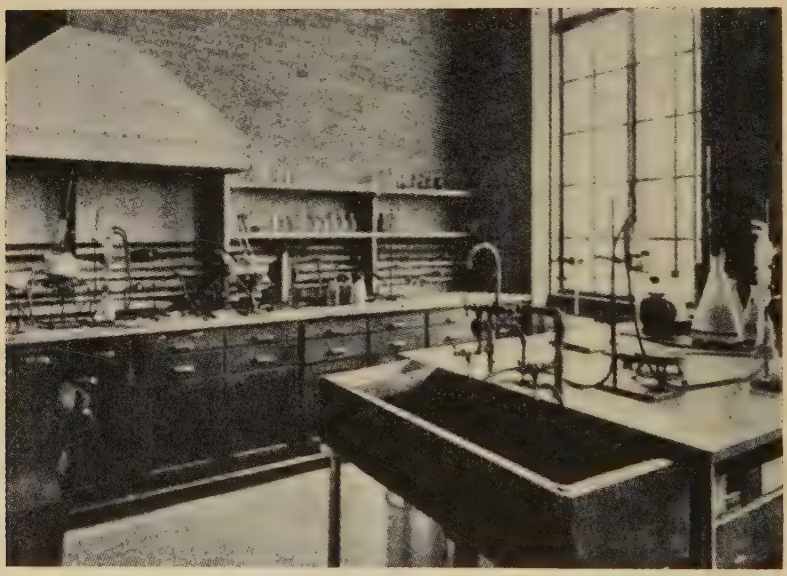

Fig. 62. Assistant's Laboratory, Wesleyan University

and cupboards below. On the other side of the room space is found for a desk, a chair or two, book case, coat and hat locker or closet, and filing case and possibly a case for chemical apparatus and bottles. Of course, it is very desirable if every teacher can be given an office and a separate private laboratory, but this uses much space, and the combination office and laboratory serves the purpose very well. Where a separate office and private laboratory are provided it is not essential that these should be in adjoining rooms, but it is very convenient to have them arranged with a door between the two rooms.

Private Laboratories. Each instructor should be provided with a private laboratory with approximately two hundred square feet of floor space. This may be a separate room or it may be the combined office and laboratory suggested above, and equipped with the table there described. To this table should be brought as many of the piping systems of the laboratory as possible, water, gas, electricity, air, waste, etc.,—the more, the better. The dimensions of the drawers vary with local needs, those given under general tables being satisfactory. Some prefer a trough at the back of the table top with a single sink at the center or at one end of the table while others prefer only a sink or two in the table top. The trough sink might be made fifteen inches by twenty-four by eleven. Sinks in the table top without troughs may be made smaller. Drain racks, near the sinks, over radiators, or in special cupboards, are convenient.

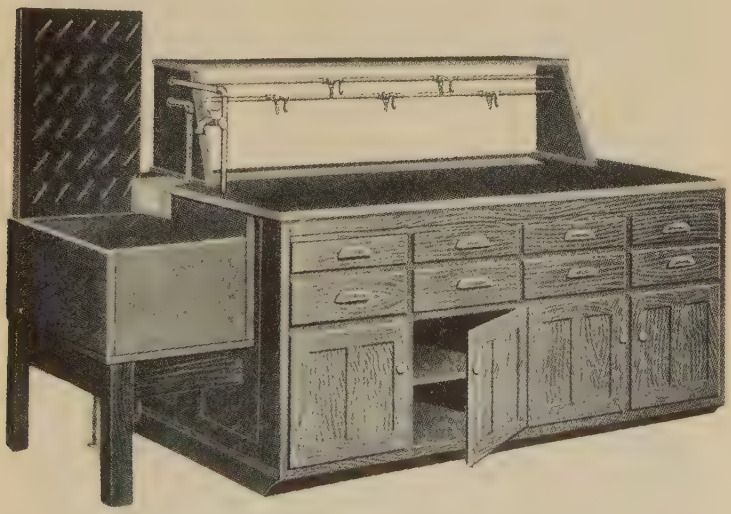

Fig. 63. Wall Table with Sink and Drain Board.

Location of Tables. It is desirable that space be provided where special apparatus may be set up for special or research work. This space should be arranged near the working table so that connections may be made to the piping brought to the table. Sometimes it is convenient to have this space on the other side of the room from the working table with the piping systems

brought through the wall from the next similar room. However, this arrangement is in general not satisfactory since it

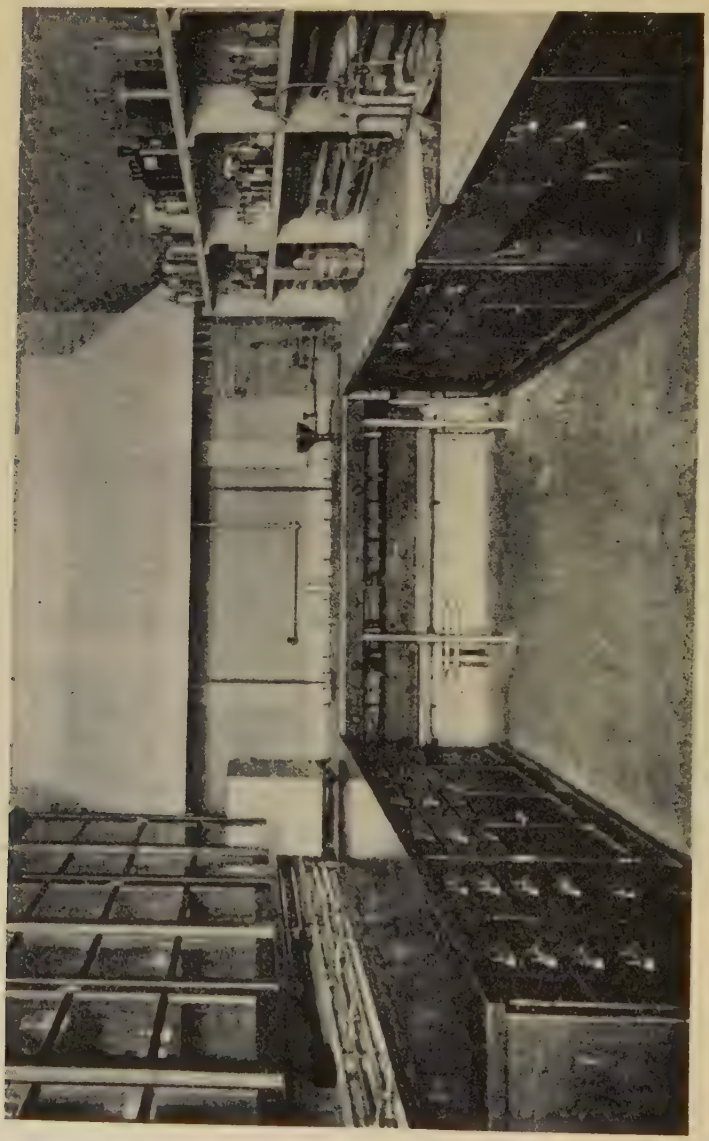

Fig. 64. Typical Research Room, Wesleyan University.

would involve bringing in water and a waste drain and would virtually mean the setting up of another table. When two pri-

vate laboratories adjoin each other it is well to have the plumbing brought to the two rooms carried on the wall between them —thus the working tables in one room would be on the right and in the other on the left. This arrangement saves much in plumbing.

A private laboratory may have in addition to the working table a case for apparatus, a balance table or shelf, a ventilating hood, and, in case it is used for an office, a desk also.

Research Laboratories. Research laboratories for graduate students are usually like the individual laboratories just described, but in case it is desired to have several work in the same room the arrangement will necessarily be more like that of other working laboratories. In this case, room tables may be substituted for wall desks, those of the type for more advanced work being used. It is well to have some space in such rooms where special apparatus may be built up which could not be erected well on top of a table. In other words, it is wise in a research room to have as much flexibility as possible both in space and in equipment.

CHAPTER XIII

LABORATORIES FOR GENERAL CHEMISTRY

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McKinley High School, Washington, D. C.

High School Laboratories for Chemistry

Types of Laboratories. It is the purpose of this chapter to set forth the commonly accepted standards of equipment for high school chemistry as determined from the replies to a questionnaire sent to a considerable number of experienced instructors in high school chemistry, and also from consultation with several laboratory experts of wide experience in advisory work relative to laboratory layouts. Three types of high school laboratories are considered; the large school which needs more than a single chemical laboratory of the 24 to 32 student type, the medium school which has pupils enough in chemistry to use a single laboratory of the above size for this subject only, and the smaller school which must use its laboratory for two or more sciences.

A school for instance with 1000 or more pupils will have from 500 to 600 enrolled in the four laboratory sciences, about 100 to 125 in chemistry, if given in the third year of the high school course, and an additional 30 to 60 if a second year in chemistry is given. These figures are based on studies in high school enrollment made by the U. S. Bureau of Education.

A high school with 100 students in first year chemistry needs laboratory tables for at least 35 students working at the same time, and preferably, tables for 50 students at a time. A program which provides for two separate students in different class sections using the same space at the laboratory table is easily made. One for three students to use the same space is possible but more difficult. Standard chemical tables are made, however,

with cupboards and drawers for three sections of students as well as for two sections.

This means that a school with more than 100 pupils in chemistry must have one laboratory larger than the 24 to 32 student standard-sized laboratory, or two or more laboratories of that size. Some instructors prefer the large laboratory, others the separate smaller laboratories. Schools with about 40 to 60 pupils in chemistry need but one laboratory of the standard size. A supply room, class demonstration and recitation room, and an office for the instructors is desirable whenever possible.

A single laboratory for chemistry and another science is not advisable, except where it is necessary in a small school. High school chemistry should be based on experimental work done during the course. The corroding fumes generated thereby are not so completely removed by ventilating systems that the instruments of other sciences are free from injury. The same difficulty arises from combination supply rooms.

The prevailing opinion regarding the two types of departments referred to favors the location of either of them on the top floor along the main corridor wherever there is the most light.

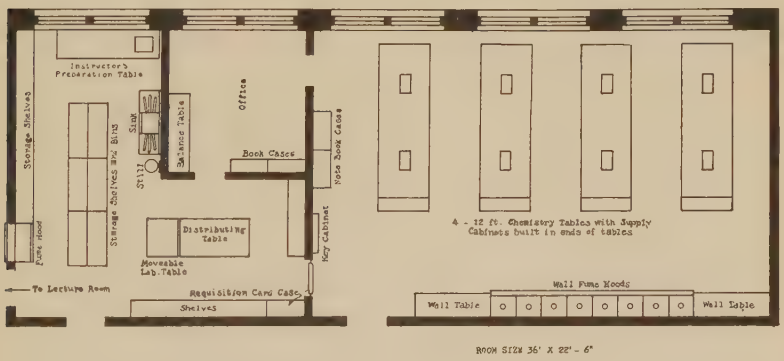

Fig. 65. Office Between Laboratory and Lecture Room.

Large Department

Location of Rooms. The location of a supply room and an office between the class room and the laboratory is generally preferred. Figure 65 represents such a plan. Supplies are thus

conveniently placed for distribution to the laboratory or the class room and the office is conveniently near.

Programs are so arranged that certain days are designated for the class room and others for the laboratory. The few occasions when it may be desirable to have students pass between the class room and the laboratory do not warrant a special passage way within the department, as the main corridor can be used for that purpose. Part of the office may be used for analytical balances which should be covered. If desired, a balance room may be constructed on the laboratory side by lessening the space occupied by the supply room and the office.

Laboratory. The advantages of a single large laboratory over two or more small ones are: it saves partition space, it gives flexibility in providing for classes of varying sizes; it makes it possible for one instructor to be in the laboratory while another one goes to the supply room; it prevents the duplication of chemical supplies other than the common reagents and apparatus at the student's table; it renders all hood space available at the same time; it gives a broadening and inspiring effect for one class to see the more advanced work of another class; and the large laboratory helps to develop the advantage of solidarity among teachers in the departmental work. Figure 65 shows a unit laboratory which may be increased to a large one or multiples of the same size.

The disadvantages of the single large laboratory for from 60 to 100 pupils is that confusion is apt to take place, particularly if enough instructors are not assigned to the room. This is increased by students going to a single supply room at one end of the laboratory for supplies. Two smaller laboratories, each in full charge of a single instructor, with the supply room between the two laboratories, does away with the confusion.

Aisle Space. No aisle space is indicated between the table and window side of the laboratory in Figure 65 but there is one wide main aisle (5½ ft.) between the ends of the four tables (12 ft. long, 4 ft. wide and 3 ft. high) and the hoods (2 ft. wide) on the corridor side. This affords ample space for general passage into the aisles (4 ft. to 5 ft. wide) between the tables which extend to the plumbing along the wall. One large aisle economizes floor space and increases table space near the window. However, many prefer two aisles, one on each side of the

laboratory. It is a good arrangement if space is available. In this case a long table 18 in. wide may be run under the windows, to be used for rough weighing, and shelving for chemicals may be placed between the windows.

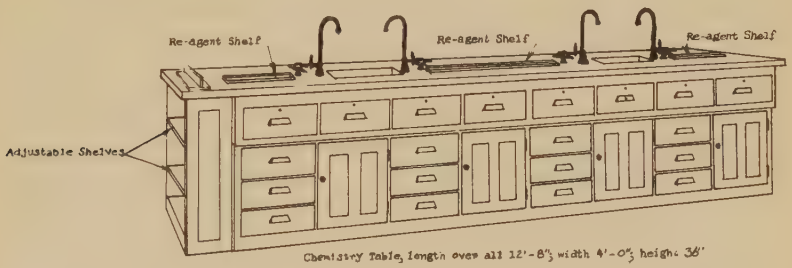

Fig. 66. Laboratory Table.

Tables. For a complete discussion of tables, see Chapter VII; Figure 66 shows the specially made type of table used in Figure 65. It provides a working space for 8 students at one time on the 5 drawer and one cupboard plan. One good sized drawer (14 in. x 6 in.) is sufficiently large to hold the apparatus generally used in a one year course of high school chemistry and one cupboard with a half shelf or a shelf on two sides gives ample space for the larger pieces of apparatus in common use by the five occupants. Some prefer several small drawers to a single large one for each student.

Location of Chemical Supplies. It is important that these be conveniently at hand at all times. The tendency is to have the reagent shelf single rather than double so that the instructor may have a clear view throughout the laboratory. Common reagents in 250 cc. bottles are usually placed on the students' desks. A complete set of chemicals (500 cc. bottles of solutions and salts) used in the entire course can be arranged on low racks with two rows of bottles at the ends of the tables. (Cf. Figure 66.) These bottles may be arranged alphabetically. This general distribution tends to prevent the congestion of students. Such a set once supplied needs little attention except for the few that are most often used. This economizes the time of both the teacher and the students in going to the supply room during laboratory hours.

Shelving may be placed along the main aisle for the distri-

bution of such supplies, yet such space is valuable for hoods and blackboards and a portion of this wall is sometimes required for wall ducts. They may be placed between the windows on the window side of the room. Scales may be kept on shelves along the windows or on the ends of the tables beneath the bottle racks and removed to the part of the table near the racks for weighing purposes, or on tables adjacent to the wall hoods.

Table Tops. (See Chapter VII.) For high schools wood tops with special treatment to make them acid-resisting, or soapstone are generally used; to a lesser extent, tile is used. The best wood tops are made of hard western birch cut in narrow slits, tongued and grooved and glued up. This prevents warping and if only the best materials are used there is little danger of cracking and joints opening. If properly treated with the so-called standard acid-resisting finish they are only slightly liable to chemical action from ordinary reagents. They should be treated with raw linseed oil several times a year and given a treatment of the original acid-resisting materials every five or six years if necessary.

The soapstone should be well selected and free from veins of limestone or other materials subject to chemical action. The tile should be vitrified and the materials in which they are laid should be supported by lead sheeting. The combined thickness of the tile and its supporting material should be approximately two inches.

Sinks. (See Chapter VII.) Soapstone, chemical stoneware, enameled cast iron and vitreous china are used in high schools with a preference for the first two. A good size for high school use is 20 in. long, 12 in. wide and 12 in. deep for end sinks on the tables, and 15 in. long, 14 in. wide and 6 in. deep for center sinks. A plug and overflow and strainer for the sink outlets are imperative as a protection to the plumbing.

Care of Waste Materials. This troublesome problem has a variety of attempted solutions, none of which will work in the midst of poor discipline. The general method is to place earthenware crocks of three to five-gallon capacity at convenient places. Some use catch jars on the tables, draining into center troughs and to the sinks, or movable sink baskets made of resistant metal, suspended in the sink under the end of the trough

or resting in the center sinks. Fiber buckets instead of crocks are sometimes used. One gallon waste jars on desks is still another method.

Keys. The general practice is for each student to have his own locker-key. In a majority of cases a key-board is placed in the laboratory under the control of the teacher who opens and closes it at the beginning and end of the laboratory period. It is sectioned to open for a group of students at a time. Each key has a number corresponding to the number of the locker. The teacher holds a master key for all locks. A number of departments have their key-board in the supply room with duplicates of all keys, and students are issued keys on a deposit. If a key is lost a duplicate is easily filed out from blanks and the student charged an extra fee for it. This relieves the daily attention of the teacher at a time when it might well be given to other matters.

Hoods. (See Chapter V.) The ventilation system supplying fresh air for the laboratory should be passed on by an engineer competent in such matters, for it is very essential to a good high school laboratory that the ordinary fumes be removed quickly and plenty of fresh air supplied to the students. In addition, fume hoods are necessary for certain experiments. One two-foot hood for every six students is satisfactory.

High school chemistry teachers seem to favor one suction fan for all hoods. This is placed in the attic and is controlled by electric switches in the laboratory. Hood bottoms in order of preference are soapstone, built-up wood tops similar to the table tops, lead and tile. The various materials used for ventilating flues are: stoneware, lead, painted sheet iron, Russian iron, tin well-painted, and tile.

High school hoods should be divided into two-foot sections. Glass or asbestos wood is preferred for the partitions. Gas cocks are inside at the rear. Hoods may be built in recesses or against the wall, the plastered walls thus forming the back of the hood. In this case baffle-plates should be used. These may be made of asbestos wood or stone and must be firmly secured at a distance of from 3 to 4 inches from the wall with openings through it at the top and bottom. It is well to give all plastered walls and asbestos boards in the hoods two coats of aluminum paint. The flues may be made of galvanized iron, not less than 20

gauge and treated on the inside with asphaltum varnish, as should also be the outside of ducts exposed to the fumes. Care should be taken to make the joints fume tight.

Supply Room

This is a place where economy of space should not be too severely exercised as supplies and their administration form an important factor in chemical instruction. This room should open into the laboratory with a split door so that the upper part can be opened while the lower part with a table board on top is closed, or better, it should have a window through which supplies are issued. A cabinet should be located near this door or window with labeled drawers for numerous items. There should also be handy drawers for beakers, funnels, test tubes, etc. Also, in a convenient place, a requisition card cabinet should be placed with a card for each student's supplies. Each card should have a signed list of the apparatus received upon entering the course, and space for entering additional articles that may be issued during the course. These cards should be numbered corresponding to those of the keys and laboratory lockers, and note book racks.

It is found advantageous by some instructors to have shelves constructed with three steps four inches high and four inches wide for chemicals as well as deep shelves for apparatus. Rolling bins and cupboards beneath the shelving serve as good storing space. With modern lighting facilities and proper location of shelves with respect to window light, the shelving may extend from the floor to the ceiling and can be easily reached if a rolling or portable stepladder is provided. Since chemicals can be bought to a better advantage in larger quantities, and since it is very annoying to run out of supplies in the midst of laboratory work, there should be plenty of storage space to have a surplus on hand.

Teacher's Work Table. This should be located in the supply room on the window side. All progressive teachers will want some place designated as their own where new experiments and demonstrations may be devised, and where some experimental problem in chemistry may be investigated. Also, at the opening and closing of the semester it may be used for the sorting of apparatus.

Large Sink. The supply room should have a sink approxi-

mately four feet long, two feet wide and ten inches deep with drain boards and back splash of the same material. All should be mounted on one and one quarter inch galvanized iron pipe standards so that the top of the sink shall be approximately three feet from the floor. The drain boards should be approximately two feet long and the splash back should extend the entire length of the sink and drain boards and extend sixteen inches above the sink.

Water Still. The supply room is a good place for the distilling apparatus to furnish distilled water for the laboratory. It should be so placed as to drain into the large sink. When high pressure steam from the power house is available, it may be led directly into the cooling coil and furnish a supply of distilled water. Otherwise a gas or electric water still may be used and if properly constructed and installed is not a fire hazard.

Office. The office should be sufficiently large so that each teacher may have a desk and so that a cabinet for records and cases for books common to all teachers of chemistry and reference books for students may be included. In case of more than one teacher of chemistry a large office for all teachers seems better than a small one for each teacher. Conferences and departmental solidarity may thus be promoted to better advantage.

Balance Room

(See Chapter XVI.) High school teachers are about equally divided on the matter of having a balance room. The proper care of a high grade balance demands protection from the atmosphere of a general laboratory. Scales sufficiently accurate for general high school work may be obtained for from $12 to $15. Several very sensitive balances for teachers' use or that of an occasional student can be placed on a small, well-supported wall table in the office. They should be protected when not in use by a frame covered with black oilcloth. Of those high school teachers advocating a balance room the average opinion as to the size is 14x10 ft. Balance tables should be 39 inches high and 18 inches wide, firmly supported along the sides of the room or a table double that width along the center of the room.

Class and Demonstration Room

It is estimated that a room 30x22 ft. with an aisle on each side 3 feet wide and allowing 22 inches square for

a chair will be large enough to seat 36 students. Should the seats be raised, the first elevation for chairs should begin at least 4 feet in front of the class room table and these elevations, 4 inches to 6 inches high and 36 inches wide, should continue to the rear

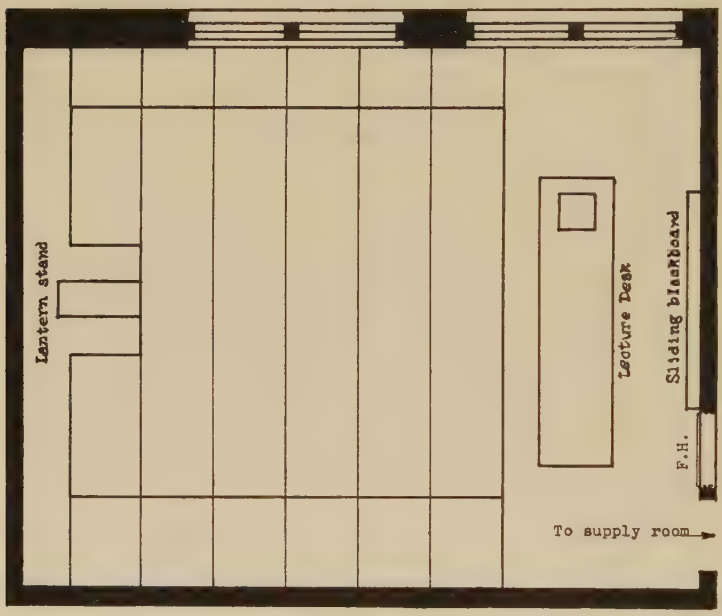

Fig. 67. Class and Demonstration Room.

of the room. However, a room of this size scarcely needs raised seats. In the rear of the demonstration table a door should open into the supply room. A sliding blackboard at the rear of the demonstration table is a convenience. A hood is also a convenience but not an essential. In some schools one is arranged with a sliding frosted window on the class room side and a clear sliding window on the supply room side. This hood can be used not only in connection with class room demonstrations but also in connection with the work table in the supply room. A door for the exit of pupils should open into the main corridor at the aisle space in front of the demonstration table, but if raised seats are not used, it may be at the front or rear.

In most common use is a demonstration table 8 to 12 feet

in length, 3 feet wide and 3 feet high, with one large sink 18 inches long, 15 inches wide and 12 inches deep, having a pneumatic shelf. Gas and electric outlets should be on the back of the table. At the rear of the room provision should be made for projection apparatus. Figures 68 and 70 are types of large laboratories.

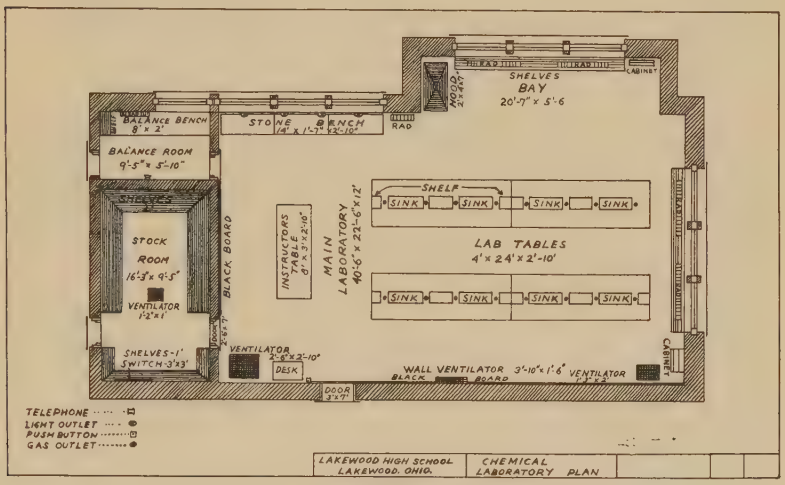

Fig. 68. Laboratory with Demonstration Table.

Small Departments

Combined Class Room and Laboratory. In small high schools the class room and chemical laboratory are often combined in one room. This is done by providing space at one end of the room for an instructor's demonstration table and for tablet arm chairs for the class, or by using the special type of furniture described below.

Figure 69 in which the location of work tables, teachers' demonstration table, wall tables, shelves, blackboard, keyboard, all with their dimensions, is given, and the sizes of the room, aisle and chair space are also stated, as well as Figures 70, 72, 75 and 76 are types of such laboratories.

This class room space in each laboratory is a decided educational advantage because of its convenience, and has been adopted in many large schools. The instructor may stop individual work at any time and assemble his class for instruction or

demonstration. He also has a place available where the more rapid workers, when they have completed their experiments, may sit and write up their notes or study, out of the way of others who are working and still under his observation. With this arrangement each laboratory requires from 25 to 35 per cent more floor space than under the old arrangement mentioned above, but the space for a separate lecture room is saved. A saving of even 25 per cent of this space may be had by using the special type furniture mentioned below.

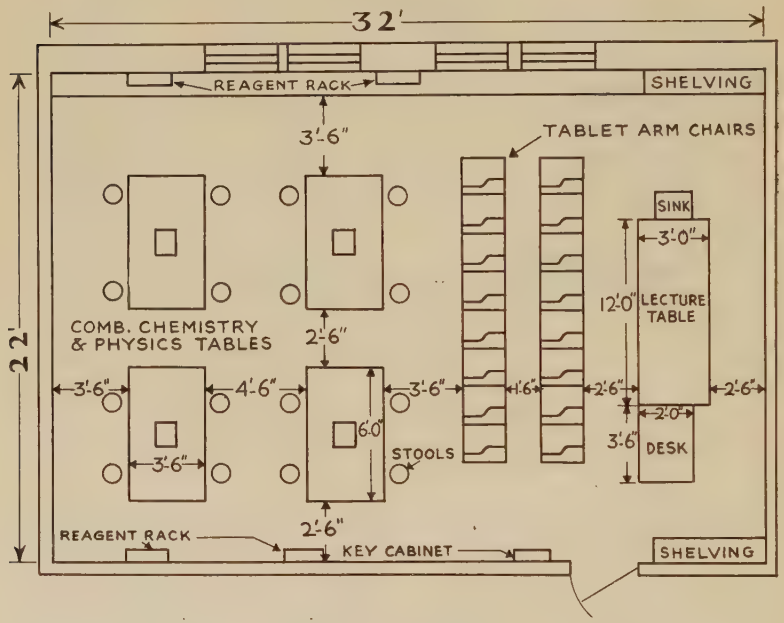

Fig. 69. Combined Class Room and Laboratory.

Special Forms of Tables. By the use of furniture especially designed for this purpose and found satisfactory during the past half-dozen years in over 1,000 high schools in the country, the student work tables may be used for seated work, and the separate lecture room or class room space at the end of the laboratory omitted. The only additional space over that necessary in the ordinary laboratory is that required for an instructor's demonstration table. This means usually a length from 6 to 8 feet more than would be required otherwise.

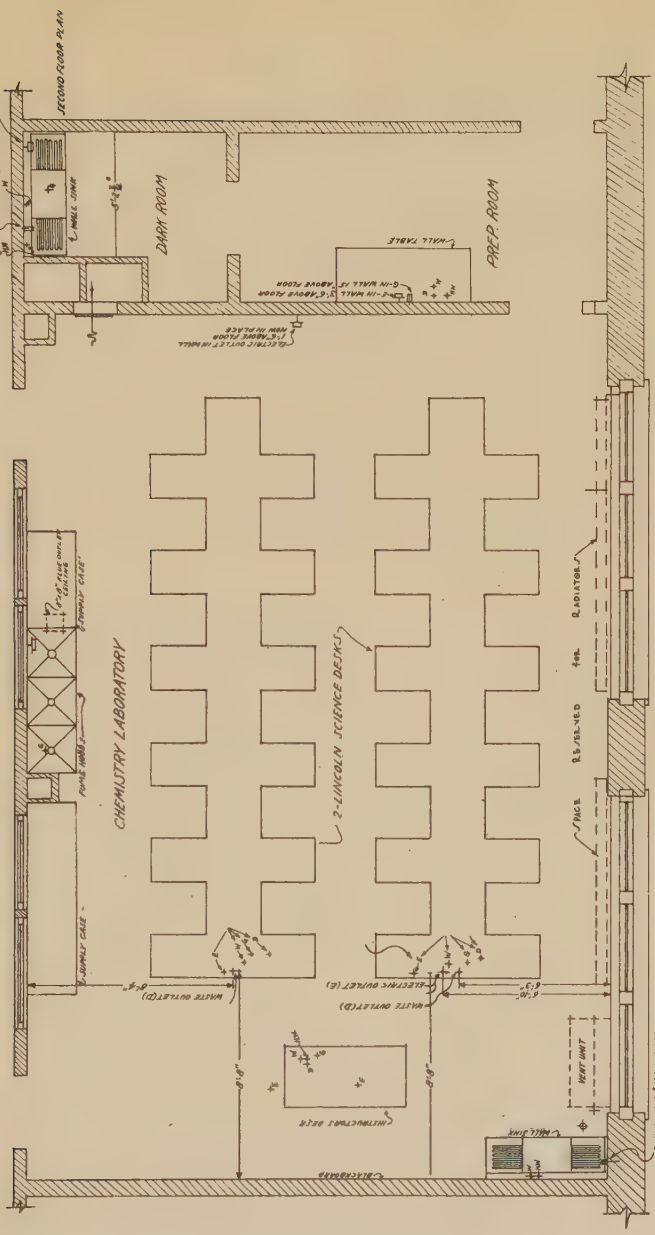

Fig. 70. High School Laboratory, Linden, N. J.

A laboratory, which is also a demonstration room, is illustrated in Figure 70. This laboratory provides space for 24 pupils. Each table is made up of T-shaped units, each unit for two students with one sink in common. All students face the in-

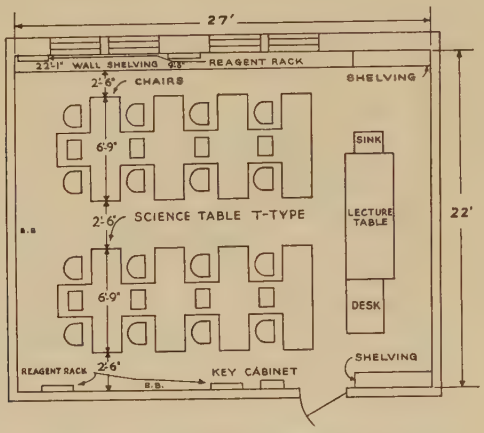

Fig. 71. Combined Laboratory and Class Room.

structor's desk. The floor plans shown indicate the general layout of the desk. The chairs for the pupils are placed under the ends of the transverse table when not in use.

Apart from the shape, these tables differ from other forms principally in height. They are 33 inches high, 3 inches higher than ordinary library tables, and 3 inches lower than other chemical tables. The height has proven satisfactory for standing pupils, and is satisfactory for sitting pupils when a special chair, two inches higher than the usual chairs, designed to accompany the furniture, is used.

Small High Schools

G. L. Coyle

Director, Department of Chemistry, Georgetown University

One of the conditions that thwarts the teaching of chemistry[1] in the smaller high schools, that is, schools with 200 or fewer

[1] Jensen, J. H. and Glenn, Earl R., "An Investigation of Types of Class Rooms for Chemistry and Other Sciences in Small High Schools," *Journal of Chemical Education*, pp. 634-644, April (1929).

pupils, is the fear of the financial burden imposed on a small community by the equipment and maintenance of a chemical laboratory, or, in fact, of any laboratory. This is a real problem, as surveys in various States show that eighty per cent of smaller high schools have less than 20 pupils in all their science classes. The outstanding need of these schools is a combination class and laboratory room which may be used for all the sciences and at the same time provides a room for any combination of subjects that the instructor may be required to teach. A type of installation for such schools is shown in Figure 72. This would reduce the floor space usually required for science teaching and also make it possible to secure a greater percentage of use than is now the case with the laboratory and class room separated. The special T-shaped furniture described above is admirably suited for this purpose. The type described here is an adaptation of it, this being available for installation in two-student sections which may be built up as needed to any capacity desired.

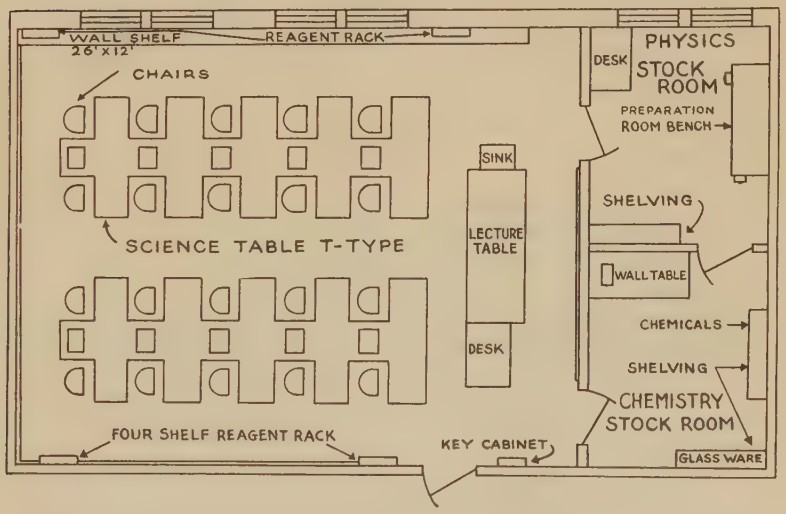

Fig. 72. Class Room Combined with Laboratory.

For this small school general laboratory a standard class room (approximately twenty-two feet wide by thirty feet long) may be used. A stock room ten feet wide and twenty-two feet

long as shown in Figure 72 should be provided.[2] The installation shown in Figure 73 can be made in units to accommodate six, eight, ten, etc., pupils up to the capacity of the room, and a small school may install the tables necessary for present needs with provision that other units for two pupils at a time may be added later. The plumbing arrangements are shown in detail in Figure 74. Where gas, water and sewer connections are lacking, the tables cost less as the sink section is omitted, though provision is made for later addition of these commodities. Gasoline gas-machines, large alcohol burners, or an electric cone heater may serve as a source of heat. The drawer arrangement is such that the apparatus for the students of the different sciences may be accommodated under separate locks. Hoods need not be installed at first, as a survey of elementary science teaching shows that only seven out of a possible forty to fifty experiments require

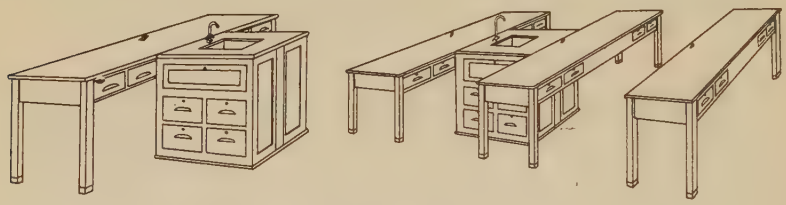

Fig. 73. The Assembly of the Unit.

a hood, and in its absence, these experiments may be delegated to the more careful instructor for demonstration, or, at times, a window hood such as described by Professor Lisk[3] may serve the purpose. By following a purchasing program, a school with an enrollment of 200 pupils or less may spread the cost of installation over six to ten years if necessary, at an annual outlay of $325 to $190.[4] This economy will be furthered much while science pupil attendance is scant, by having Freshman and Sophomores take General Science together one year and Biology

[2] Jensen and Glenn, loc. cit. pp. 640-641, where the authors give detailed lists of equipment and cost which are too long for reproduction here. Other serviceable lists are to be found in "Laboratory Layouts for the High School Sciences" by A. C. Monahan, Bureau of Education, *Bulletin No. 22*, 1927, pp. 19-22 and p. 31.

[3] Lisk, G. M., "Cheap and Serviceable Ventilating Hood," *School Science and Mathematics*. 19. 721-722 (1919).

[4] See U. S. Bureau of Education, *Bulletin No. 22*, 1927, "Laboratory Layouts for High School Sciences."

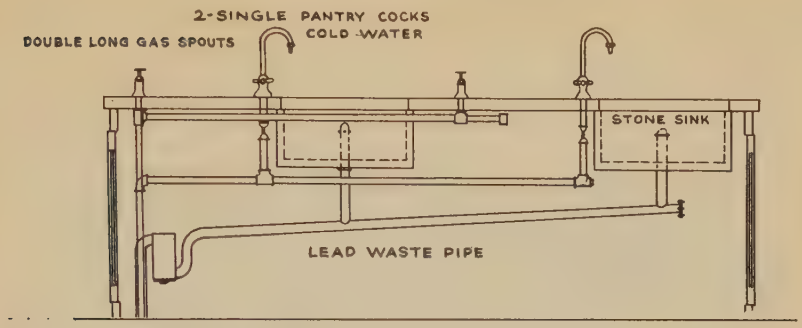

Fig. 74. Plumbing Details of Unit Table.

in the alternate year, and Physics and Chemistry alternate for the two upper classes. Biology and Chemistry should be given in the same year, as very little of the Biology equipment will be affected by chemical fumes left in the laboratory by a class in

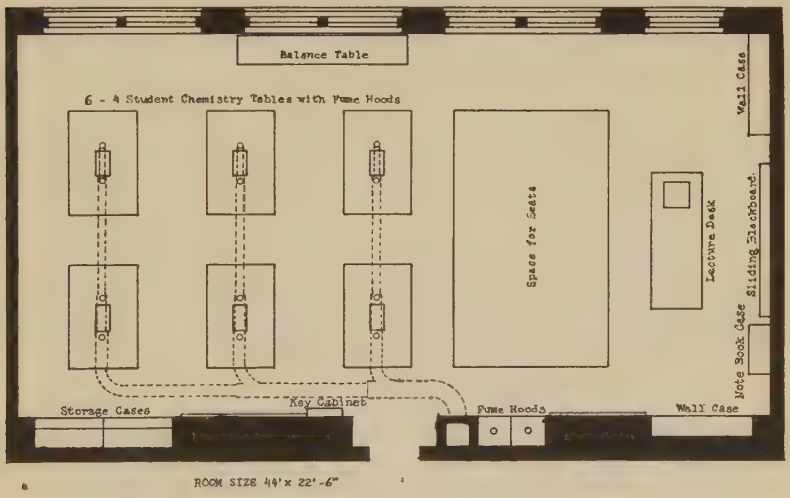

Fig. 75. Combined Lecture Room and Laboratory.

Chemistry. The drawers in these T-tables provide storage for the years when the apparatus is not in use.

College Laboratories for General Chemistry

J. N. Swan

Director, Department of Chemistry, University of Mississippi

Size of Rooms. In the college as in the large high schools, either one of two plans may be followed. One is to have a room

large enough to accommodate from 30 to 36 students at a time. This gives one instructor complete charge of all in the room and one section of students is not bothered by some other section which may be doing different work. All announcements and directions apply to all in the room. Since the room is small, the general confusion is small. The distance to reagent shelves and other general supplies in the room is not great. The other plan

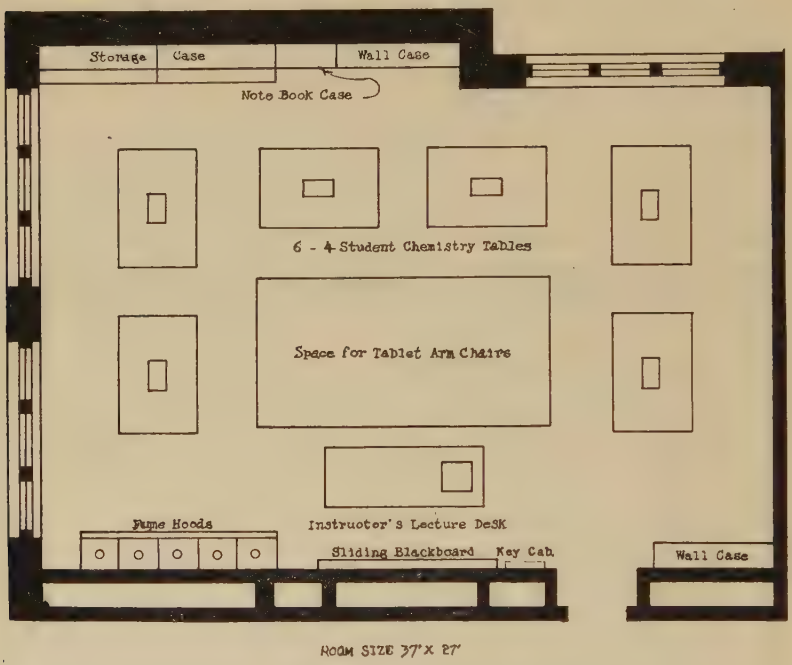

Fig. 76. Combined Class Room and Laboratory.

is to have a large room where several sections may be at work at the same time, with a professor in charge and as many assistants as needed. Sections may be segregated in part of the room or they may be united in a single large group. The arguments in favor of using this large laboratory are the same as for the large high school laboratory already given.

Tables. Furniture for college general chemistry is about the same as for high school chemistry. Tables four feet wide and placed with a 5 to 6-foot aisle between them are usually used. They have a very simple arrangement of drawers and cupboards,

a single drawer with a cupboard below. Three feet is a common unit of working space per student and this space is divided into either two or three units of drawer and cupboard space, thus accommodating either two or three sections working at the same

Fig. 77. Chemical Laboratory with Wall Hoods, Cornell University.

space but at different times. As was shown in Chapter VII (Tables), other cupboard and drawer arrangements may be used giving place to still more sections using the same table, also the unit per student may be more than thirty-six inches.

A table for general chemistry needs only water, gas, and waste pipe. It is very convenient to have electricity and hot water on the tables, but they are not essential. Sometimes small fume

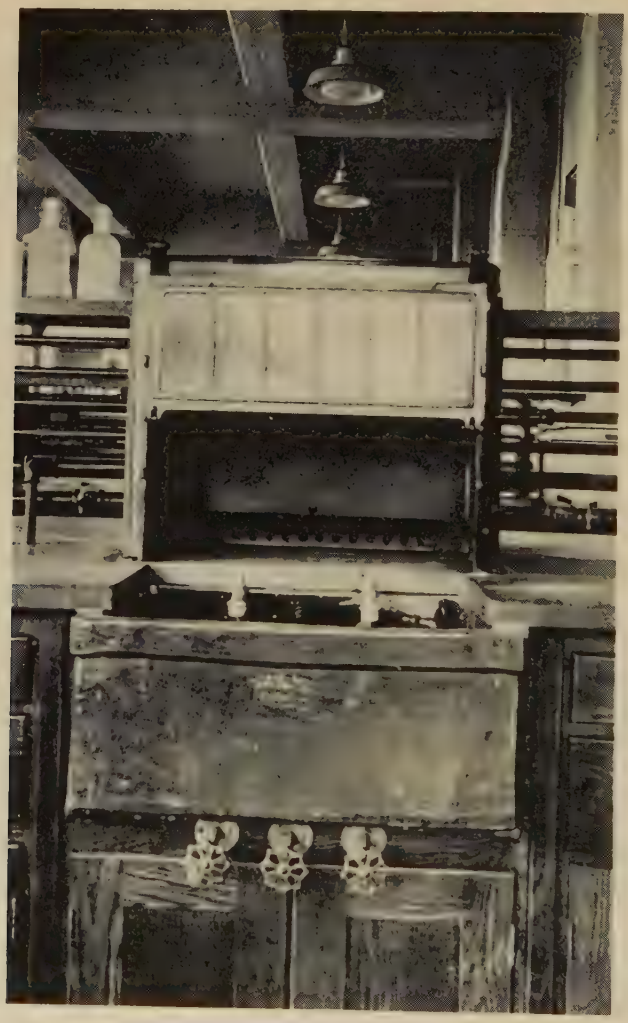

Fig. 78. Desk Hood, Harvard University.

hoods are used on these tables but wall hoods are preferred. Other details are given under the discussion of tables in Chapter VII.

The college laboratory for general chemistry should be pro-

vided with a demonstration table. This should be placed in as central a position as possible at or near the center of the inner wall. It should be placed on a platform, five or six feet square, about a foot above the floor level. It should be equipped with all the piping of the room, a small sink, and electricity. Back of the table and above it on the wall there should be a blackboard which may be seen from all over the room. This small demonstration table is used by the instructor for the performance of experiments or demonstrations and as the center of his operations while conducting the laboratory work.

Hoods. The number of wall hoods to be placed in such rooms will depend upon whether or not the desk hoods are used. In any case wall hoods are necessary for experiments where larger apparatus is used and for certain more offensive experiments, but a smaller number will suffice if desk hoods are used. In general, one two-foot hood for every four students is required.

Shelving. Reagent shelves may be placed along the walls between other fixtures. These sets of shelves may be repeated as many times as necessary to bring the reagents within easy access of all working in the room.

Notebook Rack. Another case needed is a notebook rack. This should preferably have a glass door and should be arranged with compartments for horizontal filing of notebooks. It should be located near the entrance inside the laboratory to make it convenient for students to get or leave their notebooks.

Key Cabinets. If keys are used to lock the drawers and cupboards of the laboratory table, a key cabinet will be necessary. The size of this will depend simply on the number of locks in the room. Near the entrance is the most suitable position for such a cabinet inside the room. If keyless locks are used it is obvious that this cabinet is not needed. (Cf. Chapter X.)

Sinks. These laboratories should have a general sink to which cold water, distilled water, and hot water or steam should be carried with waste pipes leading away. A suitable size for a general sink is 24 inches long, 16 inches wide, and 10 inches deep, inside measurements, though other sizes may suit very well. The sink is best with drain boards on both sides. The distilled water faucet at this sink should be clearly marked so that it would not be used for hydrant water.

Waste Receivers. Many laboratories use crocks, located con-

veniently on the floor, as waste receivers. These are unsightly and lead to messy floors. A pitcher, known in trade as a "hall boy," serves this purpose better when placed on the table. Others use waste drawers placed just below the table top, but besides being hard to empty and keep clean, they are in the way of the workers if drawn out for use. In the case of tables with a con-

Fig. 79. Table with Waste Receivers, Boston College.

tinuous trough one of the neatest types of waste receiver is a sink strainer with holes in the bottom to drain off any liquid into the trough itself. It is fitted with lugs to hold it on both sides of the trough and without interference can readily dispose of the waste of students on both sides of the table. It can be had

in stoneware, monel metal, or red metal, and may be made as long as desired.

Another method of disposing of waste is a small wall cabinet placed on a pilaster on the wall between two tables. It has a door in the upper quarter of the cabinet, and in the lower part, a metal receptacle with a pair of enclosing doors, which can be removed and emptied by the janitor at the end of the day. This type of receptacle holds considerable waste and while eliminating a number of crocks, adequately serves the purpose for two sides of adjacent tables.

Balances. Small balances should be placed near the reagent shelves for coarser weighing of chemicals. A small shelf may be attached to the end of a desk or on the wall near the shelving or a small table may be placed near the shelves. The balances should not be placed on the reagent shelves themselves as this would interfere with access to the shelves by others when one was weighing.

If finer balances are used for quantitative weighing they should be placed in another room near at hand. There are two outstanding reasons for having these in another room,—the balances are better protected, and the students from the start should be taught respect for quantitative balances. Both of these points are entirely missed if quantitative balances are placed in the working room.

Blackboards. It is an excellent thing to have some blackboards in the laboratory. These give the student a place to go and work out any problem which may come to him. It also gives a place for the instructor to show individual students or small groups any matter under discussion, and may at times serve for general notices.

Bulletin Boards. It is desirable to have a bulletin board in the laboratory in such a position that it may be consulted easily on entering the room. One form has a piece of corkboard on the back into which thumb tacks may be pressed easily. This is surrounded by a frame two or three inches deep on the inside, which supports the door. To prevent tampering with official notices or the posting of unauthorized bulletins, the faculty board should be enclosed in glass and have a lock and key. Open boards suffice for students' use. An excellent form is that used in hotels for announcements. It consists of a dark, slotted board into

which are fitted sliding, white, lettered buttons. As these notices can be read easily even at a distance, congestion around the board is avoided.

Adjunct Room. Adjoining all such laboratories there should be an adjunct room. This may be a room of about two hundred square feet floor space. It should have a working table of the private laboratory type with its services along at least a part of one side. The other side may have a set of shelving. Most of these shelves should be large enough to accommodate five-pint bottles—thirteen inches clear between shelves and a depth of ten or eleven inches. The more complete the equipment of the working table in this room is, the better. This room is for the making up of reagents, and similar work on the part of the instructor. Where the supply room is ample, it may be made a part of that.

Stools. Many teachers believe that first-year students in Chemistry should not sit during laboratory periods. Should seating be desired, the ordinary, horizontally-braced stools twenty-four inches in height may be supplied. Preference is shown in some laboratories for stools with adjustable seats and backs, though these are not as easily portable as the others.

Coat and Cloak Rooms. As college laboratory workers must have some place to lay aside their wraps and hats, coat and cloak rooms should be provided. One plan in use is to place lockers of metal or wood in the corridors adjacent to laboratories or lecture rooms, or in basement rooms devoted to this purpose. Gymnasium lockers of full height to provide for overcoats are preferable. They should be ventilated by openings near the top and bottom, and have individual locks and keys, though keyless locks may be used.

The coat room problem varies with the size and location of the institution and the type of student attendance. In cities, hooks in the corridors or open coat rooms are inadvisable as they are more likely to be disturbed than in rural districts, since they are more liable to invasion by irresponsible persons wandering through the building. Coat rooms, wherever located, give enhanced service by having a lavatory available.

CHAPTER XIV

LABORATORIES FOR ANALYTICAL CHEMISTRY

J. N. Swan

Director, Department of Chemistry, University of Mississippi

Qualitative Analysis Laboratories. The general floor plans, equipment and commodity services of a qualitative laboratory do not differ materially from the laboratory for College General Chemistry described in the previous chapter. Because of the frequent employment of hydrogen sulfide, a useful, though offensive and poisonous gas, plentiful provision of wall or desk hoods and ample general room ventilation is to be emphasized. Here, too, an adjunct or solution room with a service door into the laboratory is very necessary. Owing to the large number of test solutions and reagents handled, this room should be quite large. In this laboratory the preference seems to be for troughs on top of the tables with sinks at the end rather than sinks on top of the table.

Quantitative Analysis Laboratories. Quantitative laboratories are expected to have considerable flexibility, since analytical operations are quite varied. The major note in a quantitative laboratory is cleanliness which the room arrangements should foster. The work varies from the use of burettes in volumetric work to grinding and fusions in gravimetric work, with many other operations such as distillations and extractions. Back of it all and most prominent is the use of the balance, but this does not call for elaborate or difficult planning of rooms and equipments. At the same time it is true that carelessness in planning for the balances may handicap quantitative work very much.

Quantitative laboratories may include volumetric work, ordinary gravimetric work, organic analysis, assaying and elec-

trolytic determinations. It is usual to carry out the organic analyses and assaying work in special rooms for this purpose while the other operations are very often conducted in one and the same room usually designated as the room for Quantitative Analysis. The ideal arrangement would call for one room for volumetric work, another for ordinary gravimetric work, another for electrolytic work, etc., but it is not at all essential to have this subdivision until there is a separate room for each analysis.

We may apply to this chapter the suggestions in Chapter XIII covering the subjects of room sizes, general sinks and the service brought to them, note book racks, key cabinets, reagent shelving and reagent bottles, blackboards and bulletin boards, hence, there is no need of repetition here. Usually a smaller number of students take quantitative analysis than take general chemistry, and so the rooms need not be so many or so large as for the first-year work.

Working Tables. The trough form of working table is rather commonly used in the quantitative laboratory, although some prefer those with sinks upon the tops and still others want no sinks at all. Because of the fact that burettes and condensers are used, the form of drawer arrangement should be that which provides sufficient depth to store these instruments. The type which has a drawer extending through from one side to the other is easily the best form for the quantitative room. This is the type which was recommended for all laboratories except the first-year work and possibly for physical chemistry. These are described under the topic of "Tables in General" in Chapter VII.

Tables in this room should have water and gas carried along over the central trough, and it is desirable, but not essential, to have steam also. It is very useful, too, to have both direct and alternating currents on the tables where electrolytic work is to be done. Suction is quite necessary and may be had in either of the two forms stated in Chapter VIII. Where there is a central suction plant it is only necessary to carry the outlets to the tables. Many prefer to use aspirators, and for this reason more water outlets are placed over the central trough, some being used for water cocks and some for aspirators. On the whole this latter method is probably to be preferred, because the aspirator is immediately under the control of the one using it. When a general system is used the variations, due to the fluctuating num-

ber using the system and the danger of trouble at the main machine, are annoying. The aspirator method would call for two water outlets for each working space instead of one, unless the aspirator is to be so used. If the general suction system is used, the pipes may be carried along under the shelf with the water and gas. The electric outlets may be located also under the shelf or they may be placed in the front of the cabinet part just beneath the projecting table top. Sometimes the gas outlets or electric outlets are brought up through the table top, but this is not desirable in the trough style of tables, as this arrangement interferes with the use of the table top which is none too wide in any event.

Demonstration Table. In all laboratories having four or more working tables for students it is desirable to have a demonstration table placed where it may easily be seen from all parts of the room, and raised above the floor to a suitable height. In the quantitative rooms there should be all the outlets at this table which are used at the working tables of the room. It should have a blackboard on the wall back of the table. Equipment for these tables is given under the general discussion of tables.

Wall Tables. Where convenient there should be wall tables in the room which are to be used for coarser balances, for blast lamps and other special work. Some would carry air pressure to each working table and use the blast lamps there, while others prefer to have these segregated on the wall tables. A convenient arrangement is to have these extra tables at the ends of the room, and the hoods and shelving at the sides, but the arrangement must vary with different laboratories. These end tables are to have gas and air pressure and electric outlets of both types. There is no particular need of a regular water system here, although it would not be amiss to have a small sink with water brought to it. These tables should have soapstone tops, even though the working tables have wood tops. The gas, air, and electric outlets are most readily carried on a wall board back of and above the table. This wall board should be made of heavy wood and should be rigidly fastened to the wall. Its lower edge may be placed about six inches above the table and the board itself may have a width of twelve or fifteen inches. Not only may the piping systems be carried on this wall board, but it gives a very convenient place to attach special devices when needed. The

gas and air pressure pipes may be located near the bottom of the board while electric outlets may be placed higher up. Of course, it is possible to carry the conduits under the table and bring some up through the table and others out of the front just below the top, but the wall board is the most satisfactory method, since it leaves the table entirely free and the connections to the outlets are not hanging over the front of the table top.

Hoods. In quantitative laboratories the wall hoods take care of all experiments calling for hoods. They give space for distillations, electric or steam baths for evaporation, or for large drying ovens or other experiments which call for larger hood space. The relatively small number of minor experiments calling for hoods may be readily carried to these large hoods and, in any event, it is better to have them in the large hoods, for a quantitative room should always be free from obnoxious gases.

Adjunct Rooms. It is as desirable to have an adjunct room adjoining a quantitative laboratory as it is to have such a room adjoining all other kinds of laboratories. In this room, "unknowns" may be made up and stored, stock solutions may be prepared, and many other operations carried on which are better performed outside of the laboratory, but which should be on hand near the laboratory. This room should be equipped with a working table on one side of the room and shelving on the other side with perhaps a closed case of shelves or a cupboard. The description of the outfitting of a Private or Research Laboratory is suited to this room also.

Solution Room. In certain subjects, such as qualitative analysis, physiological chemistry and others, many solutions are used, and in some cases these are kept on hand for considerable length of time. In all laboratories, reagents are in continual use, and many of these must be made up from time to time. It is convenient to have a room suited to the making-up and storing of solutions, where they are to be kept away from the laboratories before being used. An adjunct room serves this purpose to some extent, but since it has many other uses it is better to have the solution room to itself.

The room should be fitted with a capacious sink having a large drain board on each side which may be used as a working place in the making of solutions. A table with stone top should be there also—a regular working wall table serves this purpose

very well—including hood, sinks, drawers and cupboards and water, gas and electric outlets. Distilled water should be brought to the room. Another piece of equipment sometimes used is a solution shelf which consists of an elevated shelf of soapstone with a soapstone trough about eighteen inches below the stone support.

Balance Room. By no means should the analytical balance be kept in the working laboratory, but in a room devoted to that purpose alone, which should adjoin the laboratory for which it is required, or be accessible therefrom without the necessity of crossing any stream of traffic, whence a chance collision may ruin the work of many days. This room may be made to serve two laboratories by being placed between them. A balance room is very simple in its arrangement. A room ten feet wide gives ample room for balance tables or shelves on both walls. These tables should be from eighteen to twenty inches wide, and thirty-two inches above the floor for the ordinary type of balance when used with stools of the usual height. A stool is more convenient as a seat before balances than a chair. For Chainomatic balances, the shelf or table should be forty-two inches above the floor, since with these balances the normal position of the eye should be near the middle of the vernier pillar. If it be required that students stand while weighing, the balance tables should be several inches higher, but no average height for this is easily calculated, as the very tall and very short person will both be inconvenienced. It should be noted that individuals differ in the height of their eyes when standing more than they do when sitting, hence, the standing position gives more difficulty in weighing than the sitting posture. In the matter of illumination, preference is given to large central lights over individual lights at each balance. Where very large balance rooms are required center tables may also be used, and in this case twenty feet would be the normal width of a room.

Location. Balance tables may be attached to the walls as shelves, or they may stand on feet as tables. In this latter case, it is better to have the table fastened to the wall as well as stand on its feet. In the case of concrete floors there is no particular reason for making this support a shelf, but with wooden floors it is almost necessary, since the yielding of the wooden floor would continually disturb the balance table. The top may be

made of wood, soapstone or slate. It is better to have each balance on a separate shelf or table than to have one table the length of the room, unless the top is of soapstone and fastened to the wall.

Special Analytical Rooms. Many analytical experiments are best performed in rooms especially devoted to that particular work. For this reason it is desirable to have special rooms for such work as water analysis, combustion, soil and clay analysis, gas analysis, urinary analysis, etc. Here again a suitable unit is a room with a floor space of about two hundred square feet. These rooms may be equipped much as the private or research rooms, but regular drawers and cupboards are not essential, although generally desirable. Special devices may be installed in some, as, for example, a table less than thirty-six inches high may be installed for working with burettes, or in the combustion room, a special table suitably equipped for combustions. The reasons for having separate rooms are quite evident. In water analysis, for example, it is almost out of the question to work in rooms where other analyses are in progress. These special rooms may be equipped for their particular purposes, and the students pass from one room to another as they take up the different types of experiments. There is no objection to making these special rooms larger, but manifestly they will soon use up a lot of floor space if a separate room is used for each analytic subject.

Laboratory for Gas Analysis

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General Requirements. A laboratory for gas analysis should have a north exposure, and it should be so well lighted by large windows as to render it unnecessary for the operator to turn toward the windows to make readings of burettes. The floor should be of cement covered with mastic or linoleum, and it should slope slightly toward one spot. This construction renders it easily possible to collect and take up any mercury that may have been spilled, and thus prevent not merely the loss of that metal, but also the possible poisoning of the users of the room through inhalation of the vapor of mercury.

The room should be free from steam pipes or radiators that cannot be cut off entirely when the laboratory is in use. In cold weather the radiators may be turned on until the room is brought to suitable temperature, and they should then be turned off so that the temperature throughout the room will be as uniform as possible. The tops of the work tables should, like the floor, be free from cracks. A very suitable material is soapstone. Running along the back of the table there should be a soapstone trough that slants toward a large sink that is provided with an iron "S" trap. The lower vent of this trap should be provided with a screw plug to permit the easy removal of any mercury that may collect.

Fig. 80. Gas Analysis Laboratory, Cornell University.

The water used as confining liquid in the various pieces of apparatus should have the temperature of the room, and this can easily be accomplished by placing near the ceiling of the room a

cylindrical galvanized-iron tank of about 400 liters capacity, which is equipped with a gauge glass. This tank can be filled beforehand by running water from a sink immediately below it into the tank through a small iron pipe, an overflow pipe in the top of the tank passing down into the sink. If a gas calorimeter is included in the equipment it is well to have the sink and the water tank near that apparatus. The tables for the analysis of gas mixtures by either the explosion or the combustion method should be provided with both direct and alternating current, and with suitable rheostats. A rheostat consisting of a lamp bank for 8 lamps, and a field rheostat for 40 volts and 6.4 amperes connected in series with the lamps will be found convenient, but a small step-down transformer and rheostat are also satisfactory.

It will be found convenient to have adjacent to the laboratory a smaller room containing shelves and drawers for the storage of the various forms of apparatus. This room should also provide space for mercury purifiers and stills and should have a table with a sink for the preparation of the various reagents. For instruction in gas analysis it is well to place in this smaller room large gasometers that can be filled with various gas mixtures for the student analyses. These gasometers are connected by pipes to each working place in the laboratory. It is desirable also to have oxygen piped to each working space. The laboratory equipment should, of course, include an accurate mercurial barometer.

Electro-Analysis Room. The ever-increasing connection between chemistry and physics along electrical lines calls for laboratories suited to this class of work. The usual electrolytic quantitative determinations may well be made in the ordinary quantitative laboratory, yet it may be more convenient to have a room specially equipped for this purpose to which the students may bring their electrolytic determinations, and where they will be free from disturbances and always find the proper currents at hand. A room for this purpose calls for ordinary tables for physical chemistry (Chapter XVI) with numerous electrical outlets and connections with all varieties of direct and alternating currents. This necessitates large switch-boards to give control of these currents. Though storage batteries may be used temporarily in this room, it is better to place them elsewhere and have the connections made through distributing panels. Cf. Chapter

IX for the special wiring required. Closed cases with roomy shelves are desirable in this room.

For clay and similar analyses suitable places are to be provided for large crucibles and small furnaces. This, of course, does not refer to ceramic experimentation, which must have special provision, but only to rooms for analytical work in this line. Rooms for water analysis should be as remote as possible from other laboratories to avoid contamination by fumes. Their equipment does not differ essentially from that of a private or research laboratory. Distilled water should be added to the other services brought to this room.

CHAPTER XV

LABORATORIES FOR ORGANIC CHEMISTRY

G. H. Woollett

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The General Organic Laboratory. Opinions may differ widely as to just what should constitute a course in general Organic Chemistry. However, a laboratory in which the student can carry out conveniently and efficiently the usual preparation work, qualitative tests, and simple quantitative analytical work would probably satisfy the most exacting instructor. An organic laboratory in which all of these operations may be carried out will be discussed here. Such a laboratory might better be called "the general organic suite" as several rooms will be required.

The General Laboratory Room

Location. What may be considered as a suitable location for any laboratory would qualify as a good location for the organic laboratory. As fewer students take Organic Chemistry than take General Chemistry, the organic laboratory may be placed behind the laboratory for general chemistry in its accessibility from the street. As the organic laboratory makes greater demands upon stock room service than any other, convenient location with regard to the stock room is essential unless such a room is maintained in the organic suite.

Size. No minimum size can be designated for the organic laboratory. On the other hand, a laboratory designed to accommodate more than three hundred students is liable to become unwieldly. Supervision is difficult and the room is inefficient as a workroom from the students' point of view, because of the

comparatively long distances to be covered in getting from place to place. When conditions permit, the room should not be filled to more than twenty-five per cent of its total capacity at one time. The students of each section should, of course, be distributed so as to accomplish this.

Fig. 81. Organic Laboratory, Yale University.

Ventilation and Lighting. Fresh air and plenty of daylight are desirable. Whether or not sufficient windows can be provided for ordinary lighting, the room should be provided with adequate electric lights. If there is any doubt about the windows being able to take care of the ventilation, and this is the case more often than not, forced ventilation should be provided, using a separate system of fans from that used for the hood ventilation. The organic laboratory needs more ventilation than most of the other laboratories.

Laboratory Tables. The trough type of table four feet wide and having a low sink at each end is preferred for organic work. It should be provided with one reagent shelf just high enough (about fourteen inches) above the central trough to accommodate under it the service lines called for. When such tables are arranged so that they reach the wall at one end, that end may profitably be equipped with a hood. Spacing of tables and aisles will be the same as in other laboratories. Owing to the apparatus required for distillations, extractions and combustions,

the locker space should be somewhat larger than that given to tables for General Chemistry. Above the locker should be a deep drawer, about ten inches long and four inches high, running entirely across the table, and at the top a short drawer the full width of the unit. This type of table has been described in detail elsewhere. (Chap. VII.)

Instructor's Table. An instructor's table raised above the general laboratory level and so placed as to be easily seen from the entire laboratory is a very desirable item of equipment. This table should have the same service of water, gas, steam, etc., as the laboratory tables. Such a table greatly simplifies supervision, roll taking, and demonstration work.

Plumbing to Tables. The pipe lines to the tables, except the waste pipe, may conveniently be placed one above the other under the central reagent shelf. Service to each table should certainly include gas, cold water, low pressure steam (five pounds), and waste. The steam pipe should be the lowest of the three, and the gas probably should be the highest. At least one gas outlet should be provided for each locker unit and one steam outlet for each two locker units. In addition to the regular water outlets, there should be a plentiful supply of small outlets for condensers, which may drain into the shallow troughs, or where sinks or troughs are not employed, into frequent waste cups of lead or stoneware, flush with the table top. Globe valves with wooden handles should be used on the steam lines. All of these except one half of the water outlets should be fitted for the attachment of rubber tubing. The water faucets not so equipped are to be connected with filter pumps. Drainage pegs attached at the end of the table to the reagent shelf, and over the sink, are a serviceable addition. There should also be one sink about two feet deep to permit the easy filling of nitrometers. Compressed air may be piped to the organic tables, although there is little call for it. Pipe refrigeration is unnecessary in a general organic laboratory.

Electrical Equipment. The organic laboratory tables should carry at least one, and if much electro-organic work is contemplated, two electrical conduits. If two lines are provided, one should carry the house A.C. and the other provide D.C. of variable voltage available. The D.C. line should have polarity-indicating sockets. If only one electrical line is provided, and

this is perhaps all that is necessary, it is well to have this line so arranged that either A.C. or D.C. may be sent through it.

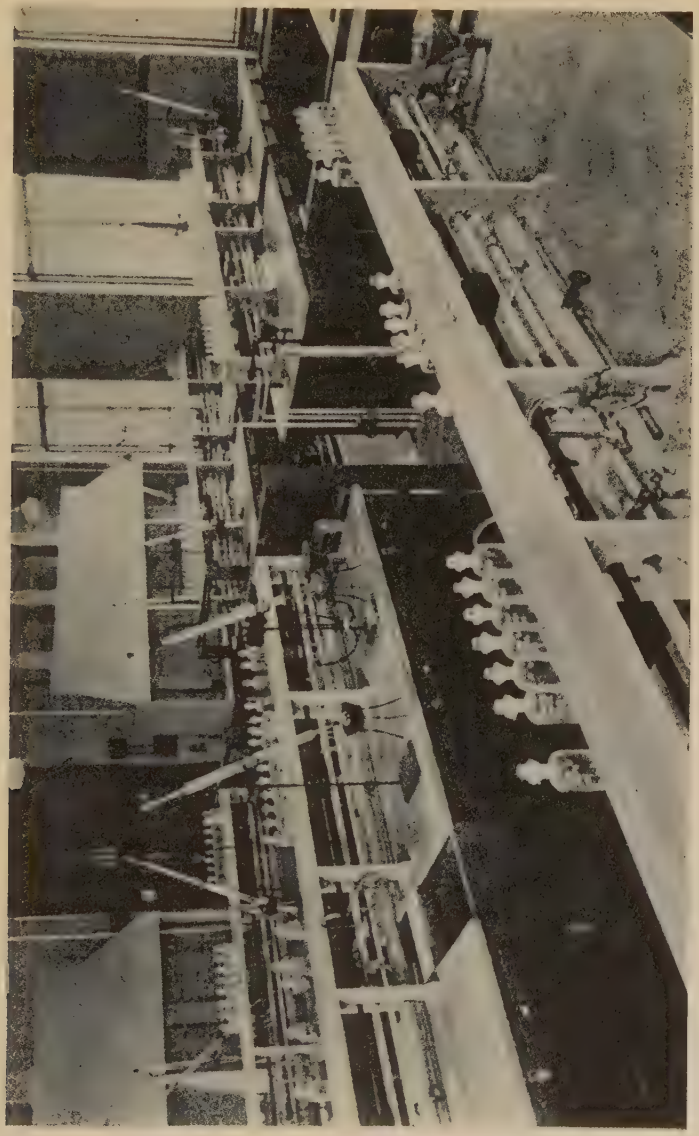

Fig. 82. Organic Laboratory Showing Steam Baths, Wesleyan University.

Steam Baths. The student should certainly be encouraged to use the laboratory steam supply whenever it is advantageous

to do so, not only for steam distillation but for steam baths and for heating water and cleaning apparatus. Fixed steam baths, though not a necessity, have been used in a number of the newer laboratories. A very serviceable steam bath can be made from the ordinary copper water bath by attaching another tubulation

Fig. 83. Laboratory for Organic Chemistry, Boston College.

under the one already present and near the bottom of the bath. Steam may be led in through the top tubulation via rubber tubing, and condensed water drained off through the lower one by the same means. If a seal is wanted it may be obtained by allowing the lower rubber tubing to dip into a small beaker of water, which may be placed in the trough. This piece of appa-

ratus works well as a steam bath and also, when the lower tubulure is stoppered, is a serviceable water bath, and in addition, can be put away in the locker.

Hoods. The small individual hood does not work well in the organic laboratory as the apparatus used in most cases is too large for such an arrangement. Wall hoods and hoods at the wall ends of the tables are decidedly better. These hoods should have at least four feet of working space above the table top. Gas, compressed air, cold water, and steam should be available. Hood space for at least one working set should be provided in the laboratory. Soapstone tops and "wire glass" sliding doors are very good, although many prefer hoods with no doors. Removable screens of wired glass are employed in some laboratories to avoid disturbing current from open windows, and sliding doors are then omitted. (Fig. 32.) Small sinks under the water and steam taps are advisable unless a trough similar to that on the tables is provided at the back of the hood. Twenty-six inches is a good width for a wall hood. A very suitable place for gas and compressed air piping is along the front of the hood below the projecting edge of the working top. Cocks are so arranged that tubing may be attached to them and passed through holes near the outer edge of the working top. If sliding doors are used, they should, of course, close outside of these holes. The part of the hood under the working table top may be enclosed to form storage cabinets, or be used for steam baths.

Very good ventilation should be provided in the hoods. Although opinions differ as to what constitutes good ventilation in hoods, a draft which will prevent the escape of fumes when the hood door is half-open should be satisfactory. It is very desirable not to have the hoods of more than one large laboratory served by one door. This question has been discussed in detail in the chapter on Hood Ventilation.

Stock Room. In smaller laboratories or those located near the general stock room, a completely equipped stock room is not necessary. In any case, a small room connected to the main laboratory is recommended which may be used as an auxiliary stock and preparation room. Stock room and combustion room, if provided, may well be connected with the main laboratory.

Balance Room. The balance room may be omitted if no

analytical work is to be done. The balance room should not be connected with the organic laboratory, or any other laboratory, but should be conveniently located nearby, with an entrance from the corridor. Equipment of the balance room will be essentially the same as that described for the quantitative analytical laboratory. The equipment of the stock room should be similar to that of the main stock room. If, however, this room is to be used mainly as a preparation room it were better equipped as recommended for a private laboratory.

Combustion Room. While a separate room for combustions is not essential, yet because of the lengthy operations involved in organic analysis, and the special equipment used to carry them out, such a room is advisable. The combustion room should be equipped with regular research laboratory tables with soapstone, slate or tile tops, and special furnace tables, without drawers or cupboards, supported on the wall by strong iron brackets or by pipe standards, and having incombustible tops, provided with gas, and at least one sink with cold water outlet. The combustion room need not be designed to accommodate more than twenty per cent of a working section at any one time. If the room is small, the tables may be arranged around the wall. In larger rooms more tables may be included. In addition to the larger gas outlets the tables should be provided with electrical outlets at convenient intervals. These outlets should be designed to carry about fifteen hundred watts each. The conduit to which the outlets are attached may be run along the wall for the wall tables and down the center of the top for the other tables. This room should be equipped with combustion furnaces, preferably of the electric type, and either gas or electrically-heated bomb furnaces protected by an iron case. Canopy or kitchen hoods over the furnaces, projecting about two and a half feet from the wall, aid in carrying off the heated air. If these hoods are made of asbestos wood, or coated with nonconducting asbestic material to prevent radiation, much inconvenience will be avoided. Other equipment for combustion such as absorption apparatus, aspirators and gas tanks should also be provided. A few blast lamps at a table with heat-resistant top, to which compressed air as well as gas is furnished should also be included. Some reagent shelving will be needed and possibly cabinets for the storage of wash bottles, nitrometers, etc.

Glass-Blowing. A wall table about twenty-four inches wide (or other table) for glass-working should be provided, with compressed air and gas, and is one of the items of equipment which may be placed in an out-of-the-way corner of the combustion room.

Bomb Room. Owing to the liability to explosions of closed tubes under pressure, a bomb room is desirable. This should adjoin the organic chemistry laboratory unless its place is taken by a table in the laboratory itself, and should be furnished with a strong iron case. The tables, arranged along the wall, should have incombustible tops and may be supported on pipe standards as cupboards and drawers are not needed here. Gas outlets should be spaced at intervals convenient to the closed-tube furnaces.

Ice Box. A heavy open box for holding ice and a means for chipping ice for use are necessary. The box should have a drain. The standard makes of refrigerators furnished by well-known firms, while scarcely sufficient to meet the needs of a large laboratory, are a distinct addition to it, and furnish ice cubes for isolated experiments. Unless the laboratory is large, or located in an isolated place, ice machines are not installed, and local dealers can supply the large blocks of ice needed.

Safety Devices. Most organic laboratory manuals recommend having about, to be used in case of fire, pails of sand, blankets, and various commercial fire extinguishers. These are no doubt of value, although most of the fires in the organic laboratory are easily handled without recourse to such equipment. A shower bath head placed in a central location, to be used in case of emergency, is also recommended. It should have a floor drain under it.

The Advanced Organic Laboratory. Laboratories for advanced organic chemistry and research should be much like the laboratories for general organic chemistry in equipment. Certain minor differences may be listed. It is essential that advanced and research students have access to a room well equipped for organic combustion and bomb heating. This may be a room opening off the main laboratory, or a separate room nearby. The same combustion room may be used by both advanced and beginning students. Relatively more reagent shelving and hood space should be provided in this laboratory.

Electrical equipment should not be omitted from advanced organic tables. Provision should be made for cooling apparatus for some time to a comparatively low temperature. The small portable electrical refrigeration units are more economical than refrigeration piped from a central plant. The raised instructor's table has no valuable function in the advanced laboratory. The advanced student handles more apparatus at one time than the elementary student and should be provided with more locker space. An auxiliary stock room is seldom needed in an advanced laboratory.

CHAPTER XVI

LABORATORIES FOR PHYSICAL AND ELECTRO-CHEMISTRY

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The department of Physical Chemistry needs room space in a chemical building as follows: 1. Laboratory or laboratories, the number of rooms being dependent on the number of classes to be handled and the nature of the course to be given; 2. An adjunct room, preferably opening directly into the laboratory, to serve as the instructor's preparation room, for storage of special apparatus, etc.; 3. Electric power room, containing batteries, motor-generator for charging, and a 1000 cycle generator; 4. Balance room. The specific needs of each of these rooms will now be considered.

Laboratory. A laboratory for physical chemistry has to be designed to accommodate a wide variety of procedures and necessitates provision for analytical work both volumetric and gravimetric, ordinary distillations, steam distillations, refluxing, the preparation of distilled water, the use of electric heating and stirring devices, suction, air pressure, the operation of thermostats, a supply of 1000 cycle current for conductivity experiments, etc. If possible, a special room should be provided for precision conductance apparatus and a precision potentiometer. Many of the units suggested as separate rooms may be housed in a single laboratory where the number of students is small or the available funds are limited. Some of the special rooms for optical work, high temperature or liquefied air experiments, dark room, gas analysis, etc., or workshop, are described in the following chapter and may also be omitted through use of the facilities of other departments of the institution. While ordinary class work

in physical chemistry does not include many experiments giving off noxious fumes, at least side-wall hoods should be installed with service of water, gas and both electrical currents. The general room equipment, therefore, would necessitate connections for gas, water (cold), waste drains, electric current (alternating and direct), air pressure and distilled water. These six are classed as essential. The following are useful where provision can be made for them:

1. **Suction.** Many instructors will prefer water suction pumps or portable vacuum pumps, to a laboratory vacuum supply, as more convenient and efficient.
2. **Steam.** Here again, many instructors will prefer having the student set up his own boiler for steam distillation experiments, heating, evaporation and general laboratory work.
3. **Hot water** or steam-mixer, useful for washing apparatus.

Since the table to be described later contains no reagent bottle shelving, wall space will be utilized for shelving, cases and blackboard. The general sink, as described for other laboratories, carries the distilled water faucet, though some think this leads to waste. Several large stands with crossbars attached by clamps will furnish sufficient support for building up apparatus at different levels. The space at the center of the room should be left as free as possible for the erection of special apparatus unless this is carried out in a separate room. The floor may be covered with mastic, linoleum, or tile.

It is important that this laboratory receive as much natural lighting as possible and where feasible it should be lighted on two or three sides. Plentiful artificial lighting should also be provided, and as a good substitute for north light, "daylight" lamps are employed for evening work and also over tables where special work is in progress which requires a uniform light. Excessive contrasts and glare may be avoided by a proper arrangement of the light fixtures. Ample closed cases for the varied apparatus of this course, and a wall shelf for reagents should also be furnished.

Table for Physical Chemistry. The distinct features desirable in a table for general class work in physical chemistry are: a maximum of flat working space; provision for a liberal supply

of water and gas, which are sometimes in continuous use day and night, for condensers and filter pumps; sinks arranged so

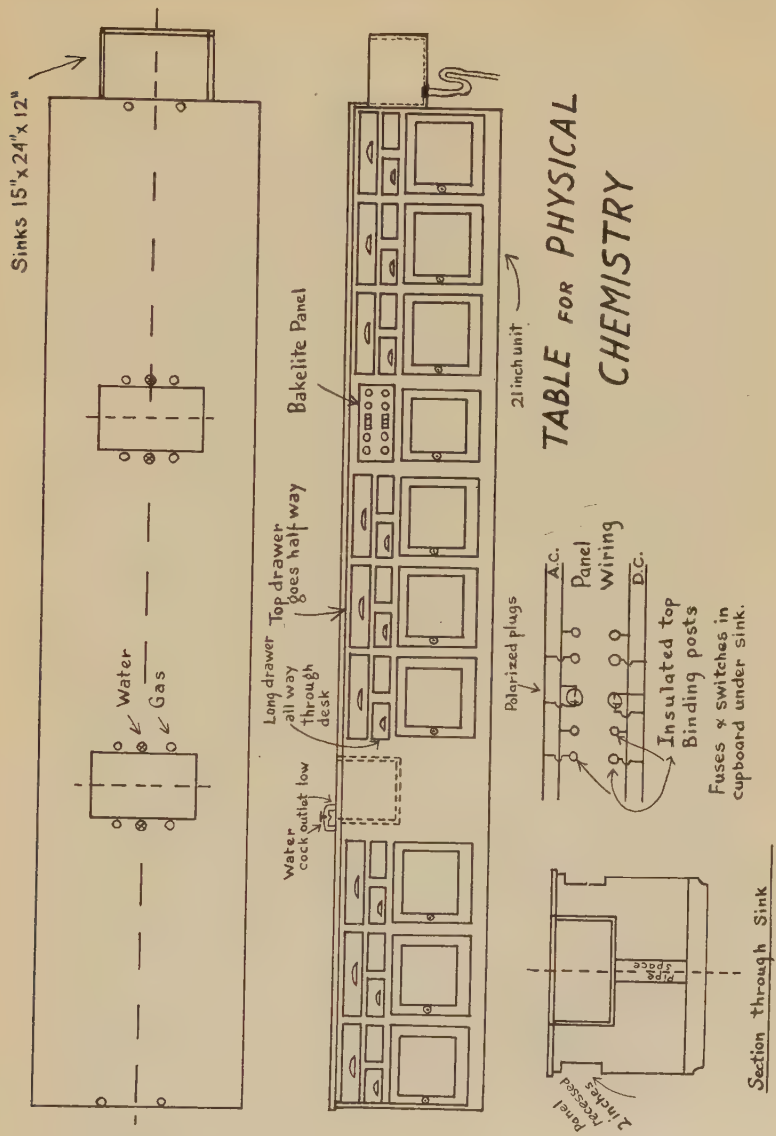

Fig. 84. Table for Physical Chemistry.

that there shall be little or no splashing on the table top when the student is washing apparatus; suitable electrical connections.

The table sketched in Figure 84 shows these features. The low end sinks are sufficient for the relatively small amount of apparatus-washing necessary. The center sinks furnish additional water connections for suction pumps or condensers and may, with detachable thermo-regulator and heater units, serve as excellent thermostats, though recent practice favors fixed thermostats at the end of the tables. With this type of table in order to keep the top clear of unnecessary obstructions the electrical connections are put on the sides, though where the tables have a reagent shelf, the outlets are best placed above the table along the shelf. It is considered advisable to include a permanently mounted reversing switch at each special D.C. outlet. The cupboard and drawer arrangement is much the same as that given for analytical and organic tables, though many dispense with the cupboards as a storage space. Students require about as much working space on tables as in a research laboratory.

In many laboratories to secure the greatest effect from window-lighting, the tables with drawers but without cupboards are placed as much as possible round the walls. A table with a beaded edge will prove useful for mercury experiments.

Adjunct Room. This room should be equipped with a table like that in the private laboratories except that two top drawers should be replaced by panels for electric outlets. The fuses for these outlets should be placed inside the adjoining cupboards. The opposite side of the room should be fitted with approximately half-open shelving for bottles, flasks, tubing and apparatus not needing especial protection from dust, and the other half fitted with glass door cases and used for storing special apparatus. The dimensions of the shelving may be varied within rather wide limits, owing to the diversity of apparatus to be stored. The glass door cases are commonly built with movable shelves so that the height can be varied to suit the apparatus at hand. As in the case of the open shelving, a generous depth is desirable.

Electric Power Room. (Cf. Chapter IX.) The necessary units in this room are: a motor-generator for charging batteries and furnishing direct current power; a set of storage batteries totaling thirty volts as a minimum, one hundred ten volts preferable (these are better located in a separate, well-ventilated room); a switch-board arranged to connect the battery on the

D.C. line in six volt steps, to connect the generator directly on the line, or to the battery for charging; and to connect the 1000 cycle generator to the D.C. line. It is possible when the battery is not too large to charge it from a large Rectigon or Tungar

Fig. 85. Laboratory for Electro-Chemistry, Cornell University.

and thus to eliminate the motor-generator. The actual mounting of these units should be made according to the directions of the manufacturers of the equipment. If this room is located near the source of power, the outlay for heavy electrical cables is

reduced. A laboratory of physical chemistry should have *maximum* flexibility because times and methods change and a highly specialized laboratory is a mistake.

Balance Room. The balance room for physical chemistry is the same as for analytical except that a barometer should be included as a part of its equipment. In case of necessity, since there are practically no fumes in the laboratory, balances may be kept here, along the inner wall to avoid disturbance from radiation.

Constant Temperature Room. The necessity for constant temperature rooms has been largely removed by the employment of constant temperature baths and ovens. However, some lines of experimentation call for larger space than these instruments afford. This need is met by building an insulated room within a room, usually in the basement, owing to difficulty in controlling the natural variations of temperature. The lower down and less exposed to the sun and wind, the less is the need for elaborate construction. This location involves little inconvenience as this room is used only intermittently. The floor, ceiling, and double walls with an air space between them, are all insulated by good non-conducting material. There should be two doors with a lobby between them to provide entrance without disturbance of temperature, and carefully controlled ventilation is also necessary.

If the room is wholly interior it may only be necessary to install an electric heating device, automatically controlled, near the floor. If a refrigerating device is employed for lower temperatures, it should be installed in the upper part of the room. Automatic control of heating and cooling systems is not generally employed as it is somewhat costly in operation, and most frequently does not justify the expense of its installation. Fans or other devices for circulating the air should be employed to maintain a uniform temperature over the whole room.

Tables, equipped with outlets for both electric currents, air pressure, gas and water, will serve as supports for working apparatus.

CHAPTER XVII

SPECIAL LABORATORIES

When space permits and the number of students justifies, or the courses offered require, there are a number of special rooms that should be provided for in the moderate-sized laboratory building, whereas in the larger institutions these subjects might have lecture or class rooms of their own, and constitute a separate department. Brief descriptions of the most important types are here given and their special features noted.

I. Laboratories for Chemical Microscopy

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Professor of Chemical Microscopy, Cornell University

Location. Since a laboratory of chemical microscopy serves largely as a clearing house for the solution of unusual problems originating in all the other divisional laboratories of an institute devoted mainly to chemical research, a central location in the building will best serve the interests of all. Chemical microscopy is more of a tool to work with and the laboratory a general utility work-shop than a special field or division, and therefore much of the research carried on in such a laboratory will be of a more or less cooperative nature. But if the laboratory is planned primarily for instructional courses, a central location becomes of secondary importance.

Experience has shown that it is decidedly advantageous to locate a laboratory for microscopy either on the upper stories of a building or on a side where the nearest trees or neighboring walls are at a sufficient distance away to permit light to be taken from the sky and reflected through the microscope by its mirror, thus precluding annoying colors and images of trees, etc., being

projected into the plane of the object lying upon the stage of the microscope.

More important still than the elimination of adventitious colors and images is that a laboratory situated high up, or permitting a distant view through its windows, provides an unfailing antidote for that bane of the inexperienced microscopist—eye fatigue. To induce the worker to rest his eyes from time to time by looking out of the window at distant objects, the window sills should be about level with the microscope table top and the table itself should be so placed as to permit him to view distant objects without rising from his chair. The windows themselves should be large, free from mullions and the glass free from striae. Floors and walls should be free from vibration if high powers are to be used and especially if photomicrographs are to be made.

Orientation. Daylight is still to be preferred for microscopic illumination, although excellent electric lamps are now obtainable with ray-filters transmitting light so nearly equivalent to daylight that even multicolored preparations can be satisfactorily studied.

A northern exposure is desirable. Other exposures are frequently subject to glare from the sky, from sunshine entering the room and annoying reflections from polished objects. Shades in the windows then become a necessity. But shades prevent the worker from looking out of the window when fatigued. North sky light is less important as to quality than that such an orientation obviates the use of shades in the windows.

Work Tables. In the selection of a design or type of table for chemical microscopy a number of points may well be taken into consideration.

1. The worker should feel perfectly comfortable when looking into his instrument or preparing material for examination when seated at the table.

2. As far as possible fatigue should be prevented and eye-strain eliminated.

3. The worker should have accessories, instruments and reagents within easy reach without being obliged to rise from the chair in which he is seated.

Any type of table that will meet these essentials will be found to be satisfactory.

After many years of experimentation and experience with large groups of students the writer believes that a very satisfactory solution of the work-table problem is to be found in the type of table shown in the accompanying sketches and photographs.

For most workers the most comfortable table height was found to be 28 inches, the variations being from 27 inches to 29 inches. Tables of standard height are much too high.

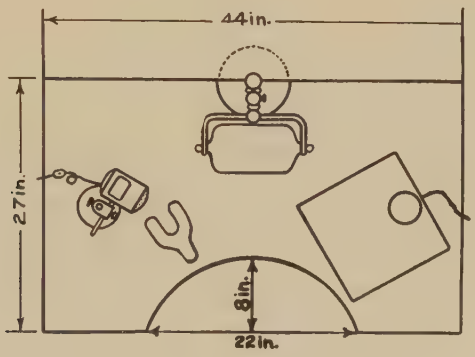


Fig. 86. Cut-out Table for Microscopy, Cornell University.

The "cut-out" shown in Fig. 86 enables the worker, when seated well into it, to rest both forearms and elbows upon the table top while moving objects on the stage of the microscope or when adding reagents to material to be tested. The most restful position is with the microscope at one side as indicated in the sketch. A table of this type presupposes a chair with swiveled seat, adjustable as to height. A satisfactory chair is any one of the numerous models of stenographer's chair which permit not only swinging about and adjustment for height from the floor but also provide for back adjustments.

Fig. 86 shows, in plan, the arrangement of microscope, lamps, burner and glass plate upon the table top that have been found convenient for work in chemical microscopy. The distribution of instruments, reagents, etc., is indicated in the photographs, Fig. 89 and Fig. 90. The dimensions given in Fig. 86 are the minimum values which the writer has found to be practicable in a student laboratory.

Figs. 87 and 88 give the elevations of this inexpensive microscope table. It will be noted that lamps with several adjust-

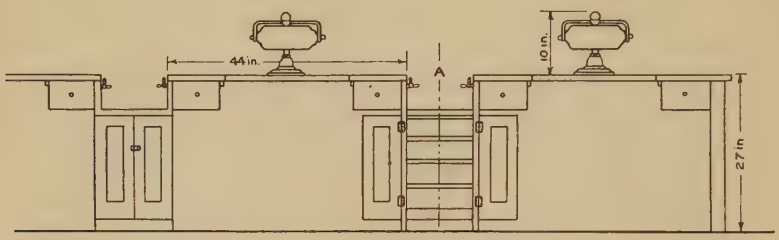


Fig. 87. Microscopy Table, Cornell University.

ments are provided for illuminating note or reference books or for manipulations. These lamps stand not over 10 inches high so that no stray light annoys the worker when looking into his instrument nor shines in the eye of other workers in the room. Providing reading lamps with "ulexit" bases increases the convenience of the work table.

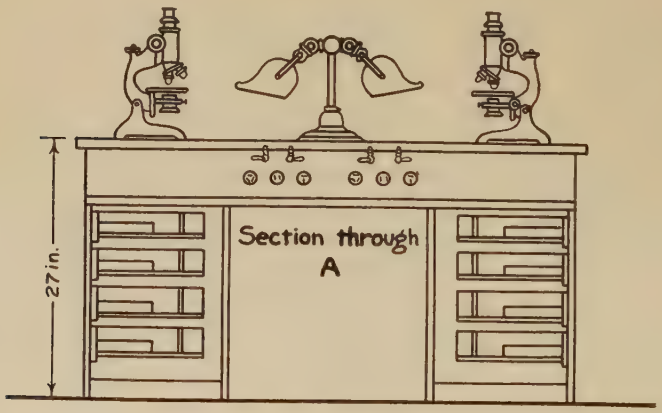


Fig. 88. Section of Table for Chemical Microscopy, Cornell University.

Table-tops should be finished dull, not glossy black, and, as far as possible, all instruments and accessories should be finished in black; see Figs. 89 and 90.

In general, it will be found more convenient for supervision and more restful on the eyes of the workers to place the work

tables so that the windows are at the side and not facing the worker. See Fig. 90.

General Equipment of the Laboratory for Chemical Microscopy. A standard height chemical work table and a small hood

Fig. 89. Chemical Microscopy Table, Cornell University.

are indispensable adjuncts and the same may be said of reagent shelves, cabinets for instruments, material for study, etc.

A small adjoining room with black walls and ceiling will be found particularly useful for investigations involving the ultramicroscope, fluorescence microscope, and photomicrography. A developing room close at hand is desirable.

Research requiring running water may be provided for in the type of microscope table described above by installing a sink and faucets in the troughs between the tables.

Alternating and direct currents should be provided whenever possible. The wiring of the D.C. should be sufficiently heavy to permit the use of currents up to 40 amperes.

One or more very low benches, 13 inches and 21 inches high, will be found useful in photomicrography when using microscope and camera in a vertical position.

Fig. 90. Laboratory for Chemical Microscopy, Cornell University.

Equipment

Chemical Microscopes each with attachable mechanical stage, Drawing Camera, Stage and Eyepiece Micrometers, Coordinate-ruled Eyepiece Micrometer, Abbe Condenser, Dark-field Condenser. 2 mm. Oil Immersion Objective.

One or more high grade Petrographic Microscopes with complete equipment.

Ultramicroscope.
Demonstration Eyepiece.
Comparison Microscope or Comparison Eyepiece.
One or more Greenough type Microscopes.

Microscope Lamps for high and low voltages, with ray filters.
Filar Micrometer.
Centrifuge.
Sliding Microtome with freezing attachment.
Apochromatic Objectives and Compensating Eyepieces for critical work.
Photomicrographic Objectives and suitable Eyepieces for the special sort of photographic work in hand.
Photomicrographic Camera.

II. A Laboratory for Chemical Spectroscopy

J. Papish

Professor of Chemical Spectroscopy, Cornell University

The walls should be painted a dark color to minimize reflection and the windows should be fitted with blinds or shutters to subdue the light. The overhead light should be controlled by a general switch and the laboratory should be provided with a sink with hot and cold water, storage cabinets with sliding doors, lockers, laboratory tables, distilled water, and a small hood.

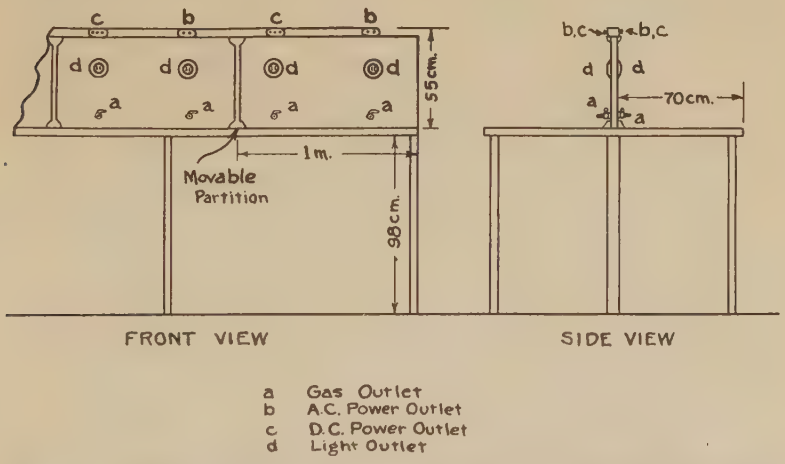


Fig. 91. Section of Table for Chemical Spectroscopy, Cornell University.

The laboratory tables should be 38½ in. high, 27½ in. wide, and should be provided with movable partitions. The tables should be fitted with gas, receptacles for electric lights, and

outlets for A.C. and D.C. currents of 110 volts. The general arrangement is shown in the diagram. The tables and the movable partitions should be painted a dull black.

The hood need not be large (43 x 28 in.), and it should be supplied with gas, air pressure, steam outlets, lighting receptacles, and outlets for A.C. and D.C. current. The hood is indispensable for work involving the study of the spectra of flames charged with volatile compounds of arsenic, selenium, and similar toxic substances. A separate small room, or rooms, should be provided for work with arc or spark spectra because the arc and high tension spark emit light that is intense enough to interfere with the other spectroscopic work; those using this equipment should wear suitable goggles for the protection of the eyes. For this work outlets for 110 and 220 volt A.C. and 110 volt D.C. should be provided as well as black, movable tables of strong construction for holding the heavy instruments.

Adjoining the laboratory for chemical spectroscopy there should be a photographic room with a maze at the entrance that is painted a dull black on both sides of the partitions. The room itself should have walls and ceiling of a light color and should be provided with a sink and drain boards, shelves for storing negatives and photographic chemicals, and lighting outlets for red, green, and white lights.

III. Other Special Rooms

J. N. Swan,

Director, Department of Chemistry, University of Mississippi

Optical Rooms. An optical room would take care of such instruments as microscopes, spectrometers, polarimeters, refractometers, colorimeters, etc. in a laboratory that does not provide special rooms devoted to these subjects, although it is better to have these instruments installed by themselves or in a room where similar instruments are used. An optical room of general character will serve this purpose in the smaller laboratories. This room is necessarily small, since if a number of students are working in it together with artificial light, it has no merits over a general laboratory.

All lighting should be under complete and easy control and some device for darkening the room is very necessary. This

may consist of spring roller curtains of black cloth operated either by hand or by small motors. To exclude light fully the edges should run in some sort of a groove in a wooden casing painted black to absorb light, and be deep and wide enough to take the curtain lath without fear of its jamming or coming out. The optical room should be equipped with a long, strong shelf, or merely brackets at intervals, to support an optical bench. In addition to a low table 28 in. high for microscopical work, and some movable tables, a laboratory table with gas, water and electrical services should be furnished. The tops of all these tables should have a dull, not glossy, black finish. Cabinets with glass doors and provided with adjustable shelving to hold the various optical instruments should be supplied. This room should have especially good ventilation as work in the dark has an oppressive effect unless relieved by a current of fresh air.

Photographic Room. Photographic work, such as copying, enlarging, making lantern slides and printing, is sometimes carried on in the Optical Room in which the necessary sink and

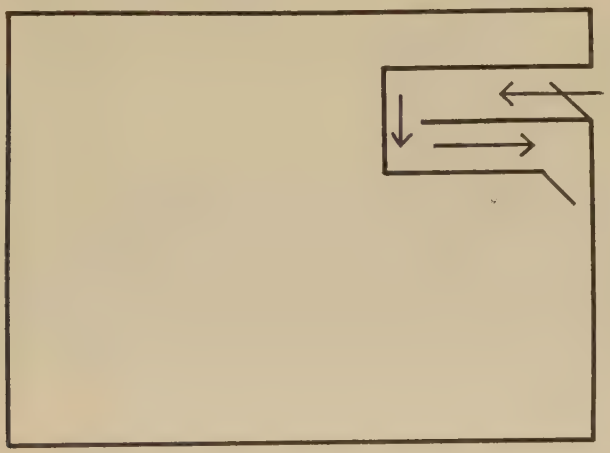


Fig. 92. Maze for Photographic Room.

supplies are provided, but a special room is desirable, or, when a course is given, a number of small rooms. The entrance to this room should have two doors, separated by a lobby, or one door fitted with a maze (Figure 92), and a window, with suitable orange-tinted screens and dark curtains. Where sensitive

plates have to be exposed, strict control of the amount of light and its quality should be possible. An ordinary laboratory table with all its equipment, not omitting a hood, is very serviceable. All but the smallest laboratories will need other movable tables, either in the middle of the room or along the wall.

The special feature of this room is an extensive photographic sink which is fairly shallow and is divided by a central partition, or use may be made of two separate narrower sinks, side by side, to which supplies of water, hot, cold and distilled, should be brought. Shelving for chemicals and closed cases for apparatus are also needed here. The room may be painted a light color, but the maze should be black.

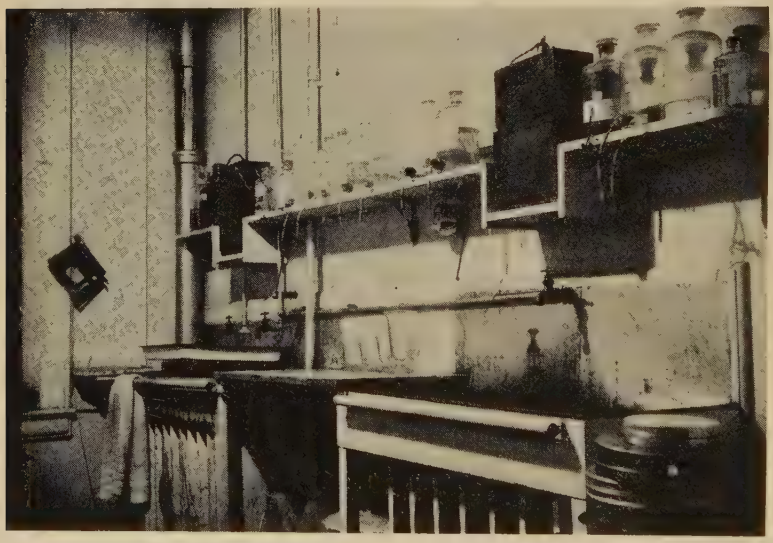


Fig. 93. Dark Room, Holy Cross College.

Dark Room. Usually adjoining a photographic room and entered through a maze therefrom, is a so-called "dark" room, though its walls may be a dull white. This room is to be fitted with a photographic sink with drain board and all water services and drainage. Beside this and not more than six inches below the windows should be located a plain developing table, preferably with a soapstone top. Another loose table with a plain top will be found a useful addition to the room. A shelf for

developers and chemicals should be placed on the wall adjacent to the developing table.

Preferably the lighting of this room is artificial, with either colored bulbs or screens to control its quality. Where daylight is admitted from an outside window this should be provided with adjustable, light-tight, frames for non-actinic or vari-colored glass screens, any one or all of which may be pushed up out of the way when not needed. As the dark room is most frequently closed to ensure protection from light, especially good ventilation is necessary. A closed case or closet to store photographic materials is desirable.

Metallurgical Laboratory. The need of a laboratory for metallurgy will depend largely on the size of the department and its opportunities for utilizing other laboratories which the institution may possess. To carry on work on the microstructure of metals, microscopic tables, which should be lower than the usual table (27 in. to 29 in.), and photographic facilities are necessary. The ordinary laboratory wall tables with soapstone or slate tops and service supplies, together with a hood, form the usual equipment. Special equipment of brick piers or tables of pipe standards with incombustible tops should be supplied for furnaces where rooms devoted to these are not employed, and in this case, the gas outlets should be large, and the electric outlets for high duty current, plentiful. The bracket for the assay balances should be made larger than usual, as these are often of greater size than the ordinary balance. Canopy hoods over the muffles or other furnaces should be employed, leading into flues to take care of the extra heat and fumes arising therefrom. The natural location of a metallurgical laboratory is adjoining the furnace room (see below), but should it be located on the floor above, a special stair connection should be made to that room. Figure 94 shows the layout of a metallurgical laboratory in a technical institute.

Furnace Room. The furnace room is usually located in the basement as low as possible to secure the maximum chimney draft and thus obtain the highest possible temperature in the furnaces. Besides, the use of ore crushers makes the basement advisable, but it should be well lighted and supplied with fresh air. Owing to the nature of the work, the fittings should be of heat-resistant materials. Brick or cement piers should be pro-

vided for the various types of furnace, and in addition to the usual ventilation, chimneys should be built to supply draft to the furnaces, and each should have dampers to equalize the draft when several furnaces are used at the same time, or to close them when not in use. The floor should be of cement, but not topped with asphalt. High-duty electric currents will be needed in addition to the usual lines and larger gas outlets should

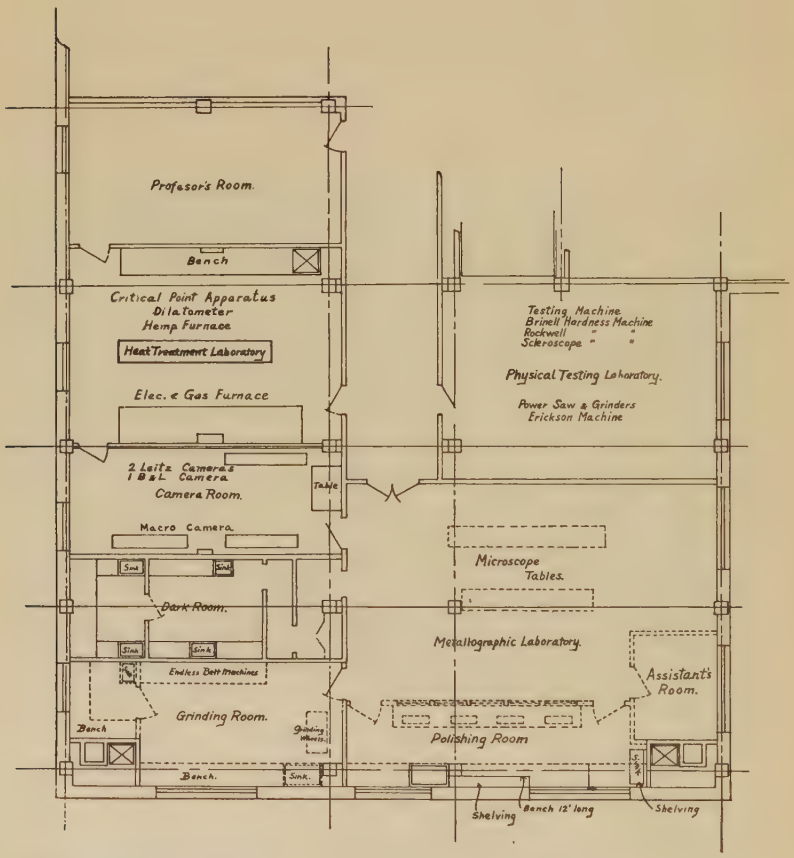
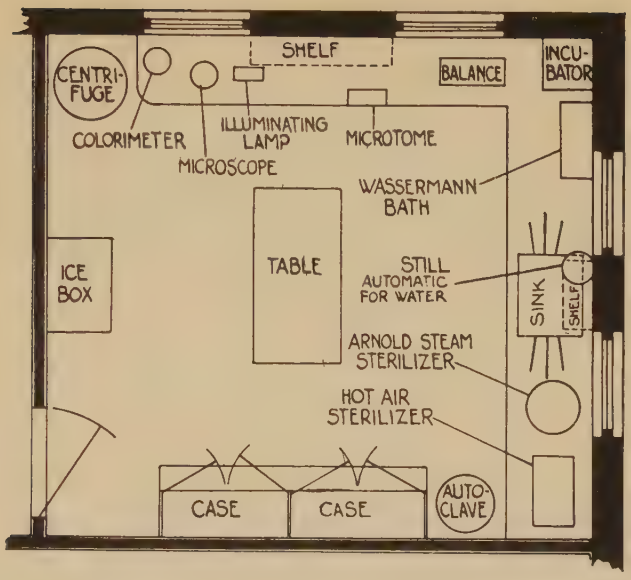
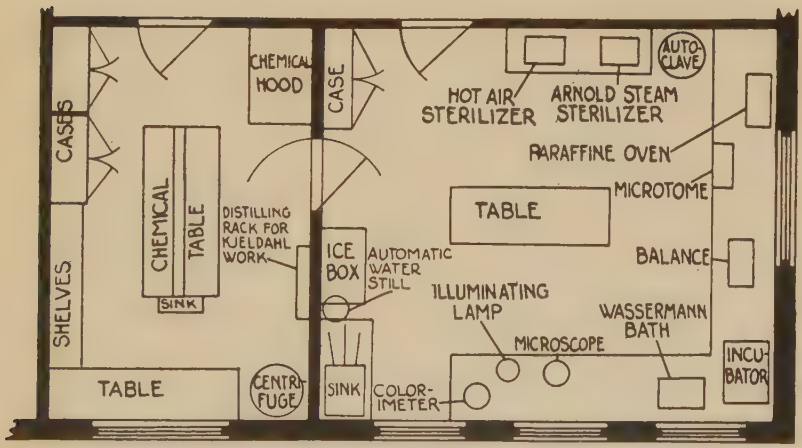


Fig. 94. Layout of Metallurgical Laboratory, Mass. Inst. of Technology.

be furnished. There should be one or two strong benches for cutting metal and using mortars and for a small milling machine. Bins should be furnished to hold the ores used in experimental work.



PLAN OF A ONE ROOM LABORATORY



PLAN OF A TWO ROOM LABORATORY

Fig. 95. Suggested Plans for a Hospital Laboratory.

Assay Rooms. This laboratory, which requires a relatively large space per worker, has the general features of a furnace room. Its special equipment of chimneys is the same and it is advisable to have canopy hoods over the gas and electric furnaces. Heat-resistant tops should be attached to the tables. The gas and electric outlets should be larger and heavier than usual on the private or research laboratory table which is fastened on one wall. Low, rugged, movable tables should also be supplied for the motor-driven crushers, grinders and mixers needed to prepare assay materials.

CHAPTER XVIII

A. THE DESIGN OF LABORATORIES FOR INSTRUCTION IN INDUSTRIAL CHEMISTRY[1]

F. H. Rhodes

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Unit Process

Introductory. The apparatus for use in a laboratory course in Industrial Chemistry should be selected and arranged in accordance with the method of instruction and the scope of the course. In some courses in Industrial Chemistry the laboratory instruction consists in the operation of a few more or less typical chemical processes on a semi-plant scale. The students assemble miniature plants for the production of sodium hydroxide or for dyeing cloth or tanning leather, and operate these plants in order to study the reactions involved and the methods by which these reactions may be effected on a manufacturing scale. In other courses, instruction in Industrial Chemistry involves the critical study of the important "Unit Operations" of chemical manufacture, such as filtration, fractional distillation, drying and gas absorption. In the latter case, the major emphasis is placed upon the development and illustration of the general fundamental theory which underlies the unit operation rather than upon the demonstration of the particular sequence of operations required to produce a specific product.

The writer is of the opinion that the method of instruction involving the study of unit operations is much more valuable and effective than that involving the study of typical manufacturing processes. Every student who goes out into industrial

[1] Owing to different views on teaching Industrial Chemistry, and the consequent effect on laboratory equipment, both methods are given.

work after graduation will be confronted with problems in filtration or distillation or other unit operations and will have occasion to apply his knowledge of the fundamental principles upon which these operations are based, but not every graduate will enter a field in which he can apply his knowledge of those particular plant processes which can be included in any ordinary course in Industrial Chemistry. Moreover, it is extremely difficult to include more than a few individual processes in a laboratory course of reasonable length, or to cover these few processes in any but a general and rather incomplete manner. For these reasons, the writer holds the opinion that laboratory instruction in Industrial Chemistry should involve the study of unit operations rather than of specific processes, and that the construction and equipment of the laboratory should be suitable for use in experiments intended to develop and demonstrate the fundamental principles underlying the common and important unit processes.

General Construction and Arrangement

I. Housing. Because of the weight of some of the pieces of equipment, the laboratory of Industrial Chemistry should be on the lowest floor of the building. The floor should be of concrete, with drainage gutters at the side. Some of the pieces of equipment, such as the evaporators, the still, the drum drier, the dormant scale, the vacuum pump, etc., must be set permanently in position. Ample working space should be provided around these fixed units. A portion of the working space in the laboratory should have a height of at least 30 feet in order to accommodate the vertical evaporator and the column still; most of the other equipment can be housed in a room 15 feet high. Long ¾-inch studs should be set at 2-foot intervals in the beams in the ceiling to permit hanging temporary shafting and piping.

II. Service Connections. The laboratory for Industrial Chemistry should be serviced with gas, cold water, high-pressure steam (at least 75 lb.), low-pressure steam (15 lb.), compressed air, direct current (110 volts), alternating current (110 volts) and vacuum. The vacuum may be supplied by the vacuum pump which is a part of the laboratory equipment. This pump should have sufficient capacity to maintain a vacuum of 29 inches on any

apparatus in the laboratory during operation. We have found it convenient to run the service mains along the ceiling of the laboratory, with take-off connections to the individual units of the apparatus. The electrical outlets may be run to fuse boxes and connection plates along the outside wall, the connections to the individual units being made by heavily insulated and armored cable. Hood flues and outlets are provided along at least one wall of the laboratory. From these outlets, temporary hoods of galvanized iron can be brought out over any apparatus which may be giving off noxious fumes.

Equipment

Special Apparatus. 1. Among the individual pieces of equipment which the writer has found to be very useful in a laboratory for instruction in Industrial Chemistry is a steel agitator, cone bottom, 35 gallons working capacity. This agitator is provided with a removable draft tube; propeller agitator driven through gears from a belt-driven shaft; and heating coil containing about 14 feet of ¾-inch wrought iron pipe arranged as a helix in the cone. The agitator is mounted permanently on steel legs. Openings are provided for bottom discharge and for the insertion of an angle thermometer at the side. The shell of the agitator is covered with two inches of magnesia insulation. We have used this piece of equipment in determining the effect of agitation upon the rate of transfer of heat, in studying the comparative efficiencies of various methods of agitation, and in demonstrating the effects of conditions during precipitation upon the character and particle size of the precipitate. We have also used the agitator as a reaction vessel in the preparation of slurries for experiments in filtration.

2. For work in fractional distillation, two stills are provided, each with a working capacity of 50 gallons. One still is heated with a closed steam coil; the other by direct gas firing. Both stills are connected to the same fractionating column, so that either kettle can discharge vapor to, and receive reflux from the column. The column itself contains 21 sections, each section carrying a single plate provided with one serrated bell and one downflow pipe. An outlet cock enters each section just at the top of the plate, so that samples may be withdrawn from

any point. Inlet connections into the vapor space are provided at three of the sections near the middle of the column, for the introduction of liquid in experiments on continuous distillation. The vapor line from the top of the column enters the condensing system. Two condensers are arranged in series, the first being a water-tube unit with straight tubes and the second being a vapor-tube coil condenser. The connecting piping is so arranged that the first condenser may be operated as a partial condenser while the second serves as a final condenser, or the total condensate can be mechanically divided into reflux and distillate so that the still can be operated by the divided flow method. Weir gauges in the reflux and distillate lines serve to measure the two parts of the condensate. Accessories and fittings include: pressure regulator on heating steam line; pressure gauges on steam line and at top of kettle; thermometers on the kettle, in the vapor line entering the column, in the vapor line leaving kettle, and in the inlet and outlet lines for cooling water; steam trap at the discharge of the heating coil; and meters for measuring the rate of flow of cooling water. The unit has a capacity of approximately 25 gallons of benzene-toluene per hour, total condensate. The entire apparatus is of steel and cast iron. Kettle, column and vapor lines are lagged with 85% magnesia.

With this equipment it is possible to demonstrate the fractional distillation of either high-boiling or low-boiling liquids, using either continuous or discontinuous distillation, with either the partial condenser or the divided flow method of control. The fractionating efficiency of the column as a whole or of a single plate can be determined, and the effects of various conditions upon the fractionating efficiency can be measured quantitatively. The change in the composition of the material as it passes up through the column can be demonstrated. The total drop in pressure through the column can be measured, and the static pressure and the friction pressure can be separately evaluated. It is possible to determine the overall thermal efficiency and the heat loss by radiation, and to measure the rate of heat transfer from steam to boiling liquid and from condensing vapor to water under various conditions.

3. In studies on evaporation, a double effect Swenson evaporator is used. One effect is a horizontal tube evaporator while the other is a vertical tube unit. The two effects are so con-

nected that either can be operated alone as a single effect, or both can be operated together as a double effect. In the latter case, either unit can be made the first effect of the pair. The installation is provided with a horizontal water-tube condenser and with closed condensate receivers so that the heating steam from the first effect and the vapor from the first effect and from the second effect can be condensed, collected and measured separately. Suitable gauges and thermometers are provided for measuring temperatures and pressures of the heating system and of the vapor from each effect.

This equipment serves not only to illustrate the methods and principles of multiple effect evaporation but also to permit the measurement of rates of transfer of heat between steam and boiling liquid and between condensing vapor and water.

4. Filtration equipment includes a plate-and-frame press, a chamber press and a rotary drum filter. The plate-and-frame press is of the washing type, with corner feed and discharge channels. It is of cast iron construction. The individual plates have a filter area of 64 square inches. Sets of frames of various thickness are provided. The chamber press is a small Sweetland "Clam-shell" filter, 10 leaves, each leaf 12 inches in diameter. Two sets of leaves are provided, one set being canvas covered and the other being covered with monel metal cloth. The rotary drum filter is a small Oliver filter, with a filtering drum 12 inches in width, canvas covered. Accessory apparatus includes pumps, pressure gauges, calibrated receivers for filtrate, etc. With this equipment, experiments can be performed to illustrate the operation of various types of filter presses, to determine the unit specific filtration resistances of various types of cakes, and to show the relation between rate of filtration and pressure, viscosity of the liquid, concentration of the slurry and the character of the precipitate. Experiments involving the use of filter aids and of precoating materials may also be performed.

5. Experiments in gas absorption are made with a steel absorption tower, 6 feet high by 1 foot diameter, provided with grid packing and with suitable inlet and outlet openings for gas and liquid and with distributing plate for liquid. Accessory apparatus includes meters for measuring rates of flow of liquid and gas, manometers, thermometers, etc. Experimental work with this tower includes the determination of the rate of absorp-

tion, in pounds of solute gas per square foot of absorbing surface per hour; and the measurement of the relationships between absorption rates and the gas velocity, liquid velocity, temperature, pressure and concentration of solute gas.

6. For experimental work on the various methods of temperature measurement there are provided rare metal and base metal thermo-couples, indicating and recording galvanometers, potentiometers and optical pyrometers. Individual experiments include the exact calibration of a rare metal couple by the use of fused salts (with determination of the most probable values of the pyrometer constants by the method of least squares), calibration of base metal couple by comparison with standard rare metal couple and by measurements made at the known melting points of various metals, demonstration of the "cold end error" and means for eliminating this error, determination of the recalescence point of a steel from the direct cooling curves and by the use of a differential couple, and determination of the missivity constants of various solid materials at different temperatures.

7. Drying equipment includes a vacuum shelf drier, a rotary drum drier and a small chamber drier. Experiments are made to develop the fundamental drying equation and to determine the effects of various conditions upon the rate of drying.

II. General Equipment. In addition to these principal pieces of special apparatus, the laboratory equipment includes centrifugal and piston pumps, motors, throttling and condensing steam calorimeters, a transmission dynamometer for measuring power input to the various pieces of apparatus, vacuum pump, scales, calibrated tanks, small (12-inch) centrifugal, Sharpless supercentrifuge, steam traps, etc. We have found the G. E. variable speed 3-phase A. C. motors very satisfactory. The types of scales which have proved most useful are (1) a dormant type dial scale, 1200-pound capacity, with graduations in both pounds and kilograms, and (2) an automatic bench scale, with 20-pound capacity on capacity beam, 10-pound capacity on the tare beam, and 20-pound capacity on the dial, dial graduated in pounds and kilograms. For measuring the power consumption of agitators, pumps, etc., we have used an electrical torsion dynamometer. With a suitable assortment of springs this instrument has a wide range and gives fairly accurate results. For many purposes,

however, a cradle dynamometer would probably be more satisfactory. We have used pot type steam traps throughout, although in some instances it is probable that expansion type or spring type traps would be somewhat better.

III. Miscellaneous. A fairly complete set of tools must be available to the students working in the laboratory. These are preferably stored in a separate room and issued on check. A good work bench with pipe vises, etc., should also be provided. Belting, shafting, small units of apparatus and repair parts should be stored in a separate room which may also serve as storage room for most of the chemicals required in the experimental work. An adequate supply of thermal insulation-block, cement and pipe covering—should be carried in stock.

A first-aid room should be available, and the instructors and assistants in the course should be trained in first-aid methods. Before each laboratory period the assistants should be given additional specific instruction in treating any injuries that are especially apt to arise.

A laboratory equipped with ordinary laboratory tables and facilities should be provided for the analysis of the raw materials used in the individual experiments and for the examination of samples taken during the experiment.

B. Laboratory for Instruction in Industrial Chemistry

Allen Rogers

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Unit Plant

In designing a laboratory for the purpose of giving practical instruction in Industrial Chemistry two general methods of procedure may be followed. The first method is to lay out the equipment on the **Unit Process** system; while the second method is to follow the **Unit Plant** idea. As the writer more strongly favors the latter, he naturally will go somewhat more into detail in its discussion, but will try to point out the merits of each.

Unit Process. In an Industrial Laboratory designed on the Unit Process system the equipment mentioned below is supposed to constitute a means for the student to become acquainted with

the general processes one meets in a typical chemical plant. There are many pieces of apparatus common to a large number of industries, but as these are of a special nature they are not considered in a unit process layout. In other words, a Unit Process system is supposed to represent in a large way the common procedures of grinding, igniting, filtering, evaporation and distillation met with by the student during his course in general chemistry or chemical engineering.

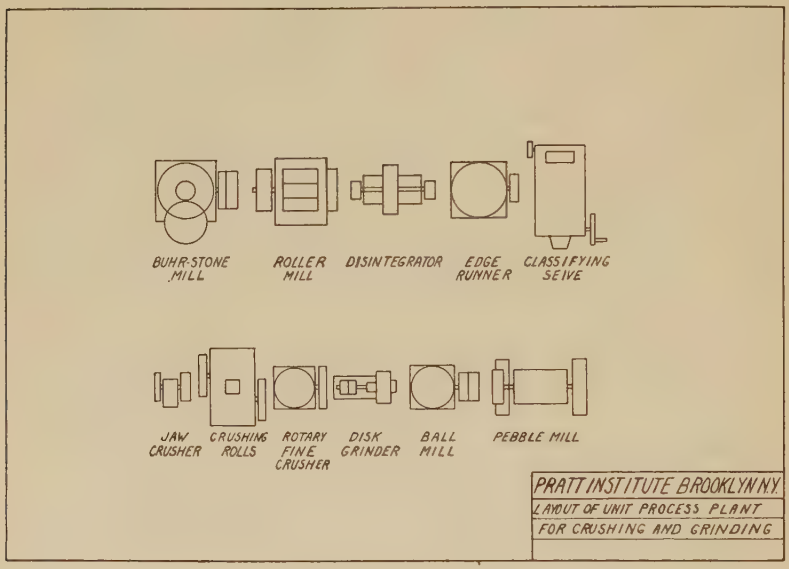

Fig. 96. Grinding Equipment.

Grinding Equipment. In the Unit Process system the equipment chosen should be of such a nature that typical operations may be demonstrated, not so much as applied to any special industry, but as a process common to many manufacturing procedures. In such a laboratory we would naturally have installed, for example, equipment for crushing and grinding. To make the instruction effective, it, of course, would be necessary to have several types of crushers and mills. These, when properly assembled and co-ordinated, would constitute a unit process group on the subject of crushing and grinding. The equipment required should consist of one or more of the following machines: Jaw crusher, crushing rolls, edge runner, disk grinder, rotary fine crusher, ball mill, pebble mill, disintegrator, buhr-stone mill and

classifying sieves. These machines should all be of such capacity that their efficiency can be studied. They should be mounted on a heavy foundation and at a sufficient height above the floor to allow for ease of loading and discharging. The unit should be connected to power in such a manner that each machine is either on an individual motor or run from its own counter shaft. The student in working with this equipment not only becomes familiar with the various machines, but in addition soon realizes under what conditions and for what material each type should be used. To save space and facilitate ease in working, the layout should be such as to allow access to all sides without crowding, with ample room in front of each machine. Such a unit is shown in Figure 96.

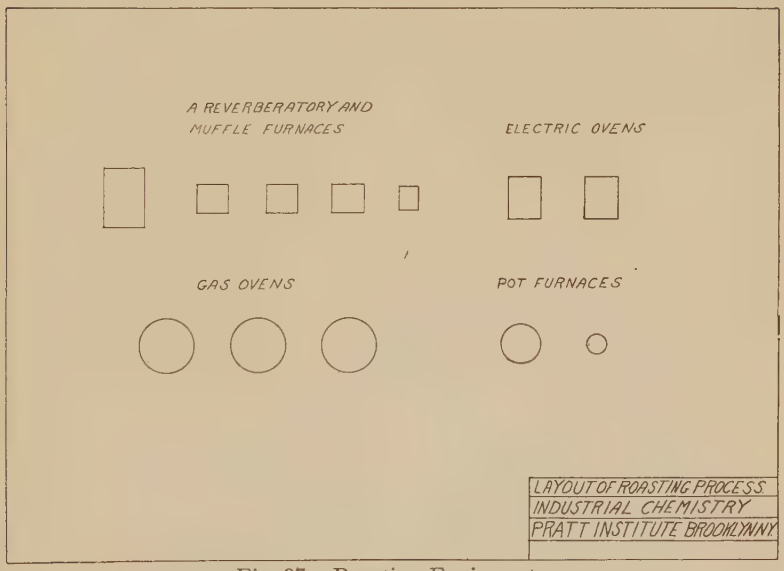

Fig. 97. Roasting Equipment.

Furnaces. As many materials must undergo roasting or burning during the process of fabrication, an equipment representing various forms of furnaces should be installed. Such a unit would consist of a pot furnace, muffle furnace, reverberatory furnace, rotary furnace, gas stoves and electric furnace. All of the furnaces should be gas heated and arranged in such a manner that the consumption of gas and temperatures obtained may be regulated and determined. In the case of the electric furnace,

better of the induction type, the current may be measured. It would be of value also to have at least one furnace heated by coal or oil.

Solution Tanks. Following grinding, or grinding and roasting, the next logical operation is that of solution. This should be demonstrated by means of various forms of tanks and kettles so arranged that either dry or live steam may be utilized. For live steam, a set of ten-gallon earthenware crocks or enamel tanks serve the purpose very admirably. Over the crocks or tanks are placed steam outlets with adjustable pipe connections. Wooden tanks or tubs may answer for the same purpose. At least one tank or crock should be fitted with a closed coil for heating with dry steam. In this unit should be several steam-jacketed kettles, some of which must be acid-resisting, and at least one provided with a mixing device. A steam heated and fire heated autoclave should also be part of the equipment.

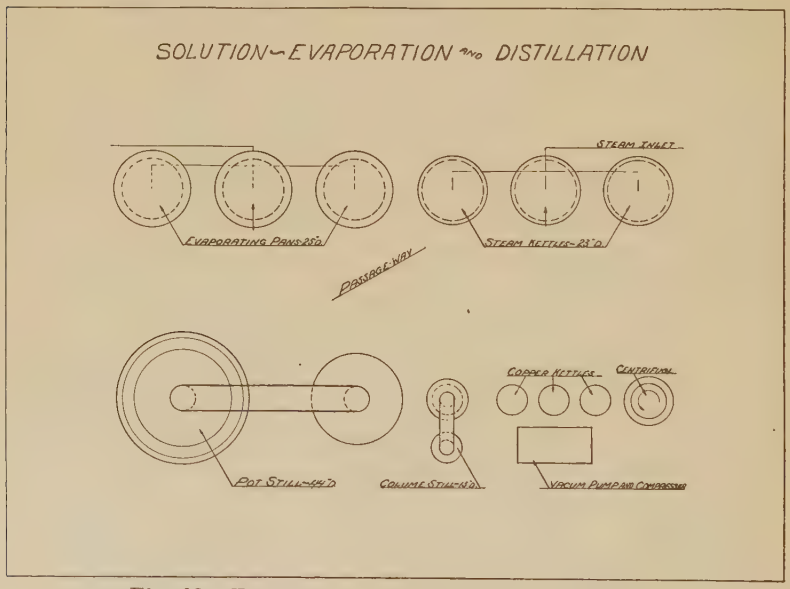

Fig. 98. Evaporating and Distillation Equipment.

Filtering and Evaporating. Solution having been accomplished, it often happens that filtration is necessary. The type of filter to be used depends upon the material under consideration. To meet the various requirements the laboratory should

be provided with bag filter, suction filter and filter press. Of the last mentioned, there are many makes available. The choice of one or more naturally rests with the individual making the layout, and will no doubt be influenced by the funds at his disposal. Evaporation may be carried out in the steam-jacketed kettles above mentioned, or special evaporating equipment provided. Earthenware evaporating dishes of five-gallon capacity are especially serviceable. These may be heated on a steam bath readily made from the lower portion of a steam-jacketed kettle, or built of galvanized sheet iron. A very convenient and simple method for evaporation consists in utilizing stoneware crocks by placing them in a water-tight tank provided with an open steam connection. For large quantities, small tubs or half-barrels may be used for the evaporating vessels. In this case, the solution is evaporated to the point of supersaturation and then transferred to the tub for slow crystallization. If funds permit, a small vacuum evaporator, of the single or multiple effect, is a very useful piece of equipment; and, of course, should be provided with steam and vacuum gauges, thermometer and peep holes. For drying purposes the laboratory should be provided with a centrifugal machine, drying oven, and vacuum dryer. These are all now carried as stock equipment by various manufacturers.

Distillation. To demonstrate the various processes of distillation the equipment should consist of a gas-heated pot still of five gallons capacity and connected to a worm condenser. For fractional distillation a steam-heated ten-gallon column still should be a part of the installation.

Unit Plant. As indicated at the beginning of this article, the writer strongly favors the Unit Plant system, and in order to justify his contention a limited discussion of the application of each piece of equipment will follow the listing of such. In the Unit Plant system the object is not only to familiarize the student with a certain piece of apparatus, but to have him realize its industrial application. To do this most effectively it has been found best to make the objective the production of some commercial article, and in so doing, incidently to acquaint him with the equipment involved. Thus a Unit Plant laboratory should be set up to represent certain typical industries, and where possible local activities should be exemplified.

To better describe this system the writer will take for his

example the Chemical Industries Laboratory at Pratt Institute. This laboratory is divided into five main units, consisting of a chemical works, soap factory, paint factory, tannery, and electroplating works. Besides these units, facilities are provided for dye testing, pigment and lake preparation, and space reserved for the erection of equipment for special problems. The size of the laboratory is forty-four by one hundred and twenty feet, gas, water, electricity, compressed air, and pressure steam being available.

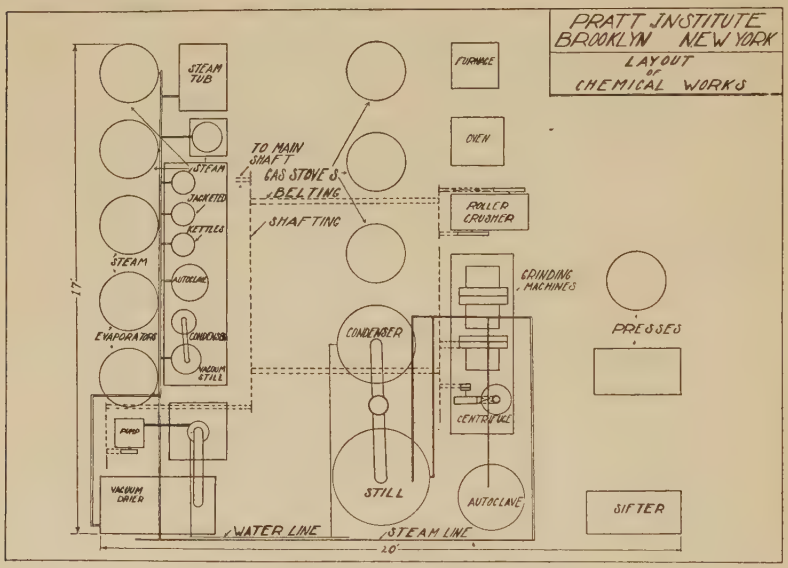

Fig. 99. Chemical Plant.

Chemical Plant. The equipment of the Chemical Works consists of the following: Jaw crusher, disk grinder, crushing rolls, classifying screens, gas-heated pot furnace, reverberatory furnace, muffle furnace, three gas stoves, three ten-gallon steam-jacketed kettles, three three-gallon steam-jacketed kettles, one one-gallon steam-jacketed kettle, one fifty-gallon pot still, one five-gallon column still, a three-gallon autoclave, vacuum driver, vacuum filter and centrifugal machine. Provision is also made for heating with live steam through connections to crocks or other vessels. The arrangement of the apparatus is shown in Figure 99 and occupies a floor space of fifteen by eighteen feet. Working facilities are provided through the center and on either

side. The equipment of this unit comprises practically all of the apparatus indicated as necessary in a unit process system, and could be used as such if desired. It has been found, however, by the writer that a better understanding can be gained by the student if he is required to operate the plant by carrying out given manufacturing processes in which as many of these machines as possible may be used.

Soap Factory Equipment. The equipment of the Soap Factory, Figure 100, consists of a lye tank, 500-pound kettle, 100-pound crutcher, slabber, cutter, chipper, drying racks, roller mill, plodder and press. In this plant both laundry and toilet soaps

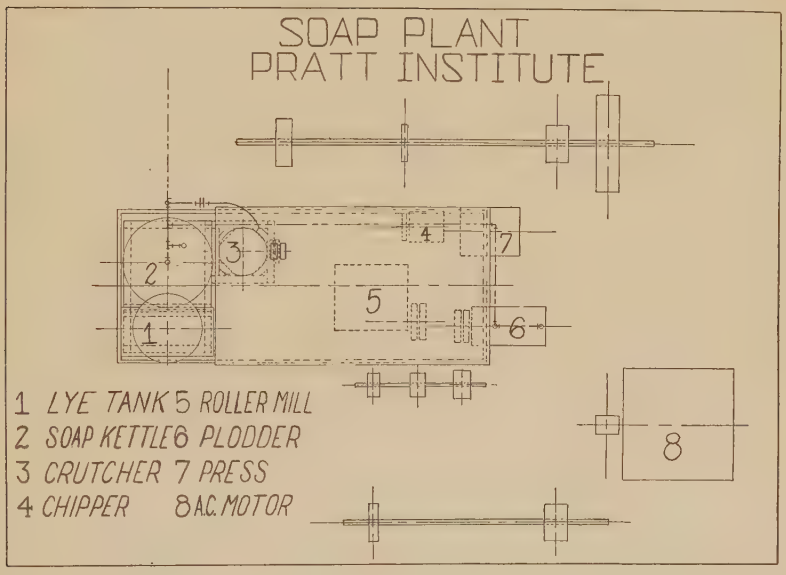

Fig. 100. Soap Plant.

are prepared under the same conditions as indicated for the chemical works. The soap factory is so built as to represent a four-story building and occupies a floor space of 18 by 5 feet with working facilities on all sides.

Tannery. The Tannery is the largest and most complete of all of the plants, as in this industry it is necessary to have quite a variety of large and special equipment. The tannery layout, Figure 101, consists of a set of soak pits, lime paddles, fleshing machine, bate paddles, pickle paddles, tan vats, tan drums, shav-

ing machine, tacking frames, belt frames, staking machine, roll-

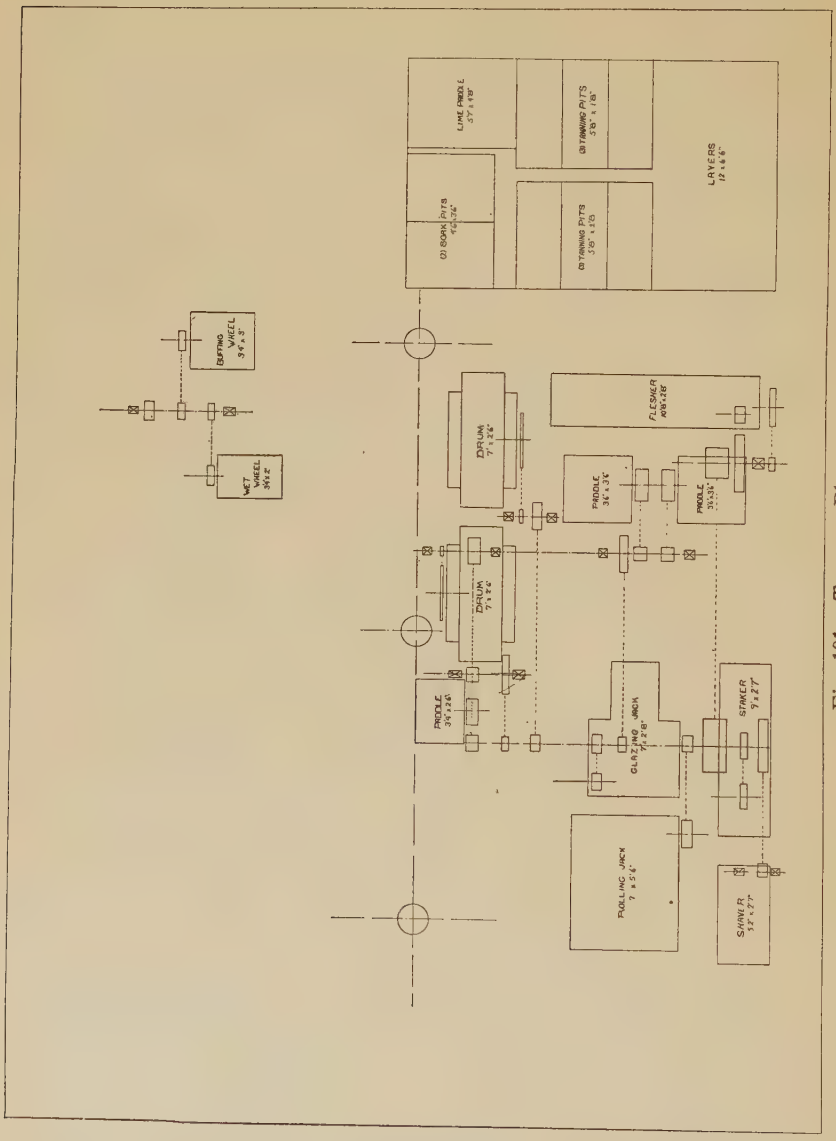

Fig. 101. Tannery Plant.

ing jack, glazing jack, wet wheel, dry wheel, milling stocks, setting tables and all necessary tools. With this equipment it

is possible to carry on the manufacture of all kinds of leather from light chamois and glove leather to heavy sole and belting.

Paint Plant. The Paint, Varnish and Lacquer Plant, Figure 102, is equipped with the following pieces of apparatus: One five-gallon change can mixer, 8 in. iron mill, two 24 inch buhr-stone mills, 20 gallon liquid mixer, 18 in. steel roller mill, double one-gallon pebble mill, fifteen gallon pebble mill, varnish kettle, plate

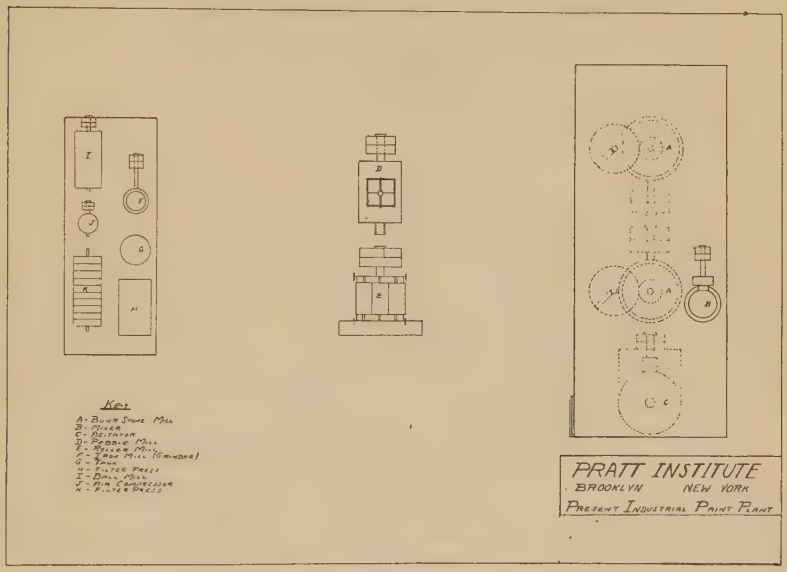

Fig. 102. Paint Plant.

filter press, disk filter press, kneading machine, and pigment precipitation tanks. In this plant it is possible to manufacture lakes, pigments, mixed paints, enamels, varnishes and lacquers. What was said in reference to the tanning course also holds true to a great degree with the special instruction in paint and varnish manufacture.

Electroplating. The electroplating equipment (Figure 103), consists of the following: Motor-generator set, switch board, tanks, tumbling barrel, and buffing wheels. The size of the equipment is such that the various types of plating may be carried out on a semi-commercial scale.

For general use with all of the plants is included a two-truck drying oven, vacuum pump and compressor. As a part of the

laboratory equipment also are two working tables for dye testing and experimental tests on lakes and pigments.

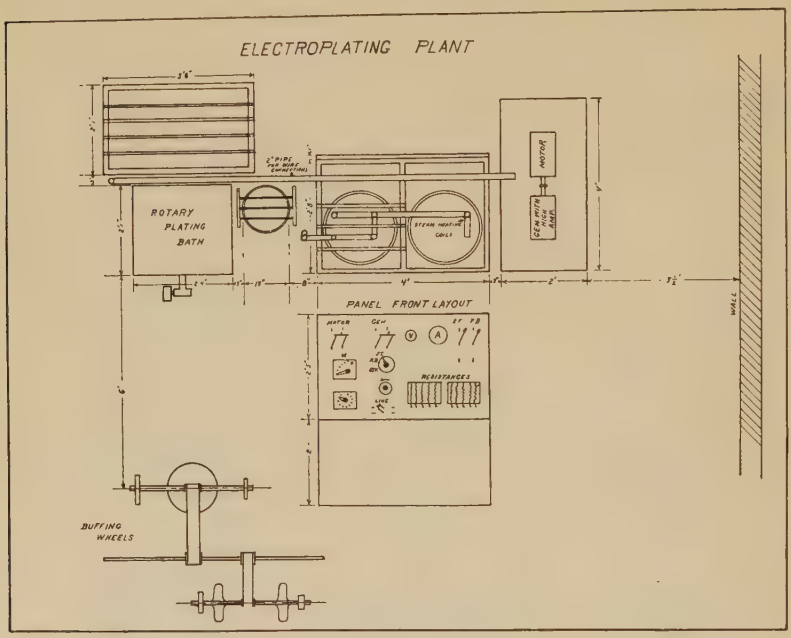

Fig. 103. Electroplating Plant.

A space of about twenty feet square is reserved for special construction purposes, such as the erection of some timely piece of equipment. A very necessary adjunct to an industrial chemical laboratory is the dry room, stock room and tool room. The last mentioned should be well supplied with the common fittings, pipes, bolts, nuts and tools for doing ordinary construction work.

The above description of a Unit Plant Laboratory is given to show an actual working model rather than a theoretical layout. It will, of course, be understood that the writer does not recommend a duplication of such an arrangement, but offers it rather as a guide. Many other industries could be chosen, but in any case the equipment should include such types as the student will be required to operate when he leaves school and takes up a position in any line of chemical industry.

CHAPTER XIX

INDUSTRIAL CHEMICAL LABORATORIES

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Introduction

The advent of the chemical laboratory into industry was marked by no noteworthy change in small-scale equipment. It was first introduced to provide analytical control of the quality of supplies, raw materials, and manufactured products, together with some experimental work looking to the improvement of products and processes and the utilization of by-products. Time has brought increasing emphasis on experimental work, which, in keeping with its growing importance, has come to be known as Industrial Research.

Industrial Research as regularly conducted is of two fairly distinct types: (1) what may be called Research proper, which employs the small-scale, laboratory equipment of academic research and differs from it mainly in objective, and (2) Development, or the experimental application of research to industry, which introduces new problems in equipment and in methods. Research introduces new and important problems in organization and arrangement, but development supplies the main reason for separate discussion of the construction and equipment of industrial chemical laboratories.

Development presents two major aspects: (a) Product Development and (b) Process Development.

Ordinarily product development goes hand in hand with process development, with emphasis on one or the other, but in their methods and equipment requirements the two differ widely.

Product development involves a study of properties and uses, leading, it may be, to exhaustive service tests, first in the laboratory and later under conditions of actual service. The purpose in any case is that of obtaining the product best suited to a specific use or a product well suited at a lower cost, or, possibly, that of finding a profitable use for a new product or by-product.

The laboratory equipment required in product development is that employed for physical and chemical tests. If these tests are those suggested by a proposed use, there may be advantage in exaggerating the severity of the conditions met in such use, in order that unpromising products may early be eliminated and only those that give fair promise of success be subjected to the test of actual service.

In process development the problem is that of reducing the cost of operation, or improving the product, or both, and, when the results of research are to be translated into commercial production, of proceeding with reasonable safety and at minimum cost from laboratory-scale to plant-scale operation.

The development of a new or improved product implies, of course, the development of a new process or one modified in respect to its operations or its raw materials.

In the exploitation of a new process, or radical modification of an existing process, success is assured only as progress is gradual. To this end process development is best undertaken in graduated steps or stages. Thus we have:

(A) First-stage, or Unit Process Development, in which the first step is taken from the small, laboratory scale to a somewhat larger scale, employing apparatus made of materials suitable for the construction of factory equipment, and large enough to make possible a proper study of yields and quality of product and give a supply of product sufficient for experimental use.

(B) Second-stage, or "Semi-works" Development, in which nearer approach is made to the conditions of commercial production by connecting in manufacturing sequence the various experimental units required.

The semi-works plant so formed better lends itself to a study of costs and to anticipation of the inevitable difficulties that come with manufacture than do the unconnected units of unit process development.

(C) Last-stage Development in which production is initiated

by the use of a unit or small group of units of the proposed full-size manufacturing equipment, in order that process and product may be standardized and the market further exploited before routine, large-scale production is undertaken.

The prospective adventurer into the field of industrial research is urged to familiarize himself with the problem of research organization and with the economic factors that serve to differentiate industrial research from that devoted solely to the advancement of knowledge. The organization of industrial research has been ably discussed,[1] but its economic aspects have received less attention except in a broad and general way. Industry everywhere is becoming convinced of the economic importance of research, but needs more detailed information concerning the character of the investment, if a program of research and development with necessary buildings and equipment is to be wisely planned.

Perhaps the first question to arise is: How much should be invested in research? It is a question not easily answered. Profits alone are not a proper basis for estimate. The size and character of the industry are better guides. A program of industrial research to be most effective should be sustained, and therefore not undertaken on a scale that cannot be maintained over periods of depression, but there is no factor to be applied to an industry's "turnover" by which the sum that may profitably be expended can be estimated.

But while industrial research is on the whole a profitable investment, the mistake must not be made of supposing that without further outlay, profits regularly begin to accrue on the completion of successful small-scale research. On the contrary, the exploitation of initially successful research generally requires large additional investment. Negative results ordinarily represent merely a relatively small investment without apparent return. Positive results, on the other hand, may suggest new products or new processes of sufficient promise to warrant development, and such development may cost many times as much as the initial research. Development, in turn, if successful, may

[1] See "Organization of Industrial Scientific Research," by C. E. K. Mees, Director of the Research Laboratory of Eastman Kodak Company, Rochester, N. Y. (McGraw-Hill).

Also "The Technical Organization, Its Development and Administration," by Weiss and Downs. (McGraw-Hill).

call for new or greatly modified manufacturing equipment, with proportionately greater outlay. If the venture is to prove profitable, manufacture must eventually yield good dividends on the whole investment.

On the other hand, there is much research that is of immediate value, particularly that which is directed toward minor improvement of process or product. Also, whether the results of research are positive and capable of profitable exploitation, or merely negative, they add to the basic knowledge of the industry and may later bring far-reaching benefits.

A point that should not be overlooked by one contemplating a program of industrial research is the considerable length of time that may elapse before getting returns commensurate with the investment and the risk. There is, of course, a wide variation in this, depending on many factors, but it is the experience of our most successful industrial research organizations that a major program of research and subsequent development may be a source of growing expense for years. Also, it should be borne in mind that the project must give reasonable promise that after transfer to commercial production it will be capable of earning profits sufficiently above those of established, competitive production to off-set the hazard and provide early return of the original investment.[2]

Thus is there wisdom in planning a program of industrial research that is not more ambitious than is warranted by the reserve funds available for the exploitation of promising research, to say nothing of the wisdom in choosing for development only such projects as appear industrially practicable and commercially assuring.

Planning a Department of Industrial Research

A successful department of industrial research is built around a man. Selection of the right man is the first and most important step in planning such a department. The man selected should first have opportunity to get acquainted with present practice and make a thorough study of his industry's needs. The necessary initial equipment may be installed in any suitable,

[2] See "The Economic Aspects of Industrial Research and Development," by L. V. Redman, Vice President and Director of Research, Bakelite Corporation. *Ind. & Eng. Chem.* Vol. 20 (1928), pp. 1242-4.

available space in which there is room for expansion, after which further equipment and help may be added as becomes necessary. The first objective in such study of the industry may well be that of better process control and minor improvement in process and product. Any research problem that may come out of such study of the industry stands a good chance, at least, of being scientifically sound and industrially feasible.[3] Of no less value is such study when a research problem comes as a "sales" suggestion.

Having a problem that is scientifically sound and which appears to be industrially feasible and commercially promising, and, having the right man and the money to exploit it, a program of industrial research is in order. Such a program, conservatively launched, may grow in its space and equipment needs to the point that a building designed and equipped for the purpose will be a paying investment. When such time comes the building problem will be mainly that of providing better facilities of the sort that experience has already shown to be of value.

While space requirements and costs vary, there may be taken as a rough guide, in planning a program of research and development, certain relationships which have been shown by experience to be reasonably constant. Stated in brief and very roughly, these are:[4]

The total floor space required may be placed at from 400 to 500 square feet per department worker. This includes laboratory work space, corridors, store rooms, space for development, office, library, etc. Under the term, "worker," are included all persons employed in the department.

The cost of the building (about $6.00 per square foot) and equipment (about $4.00 per square foot) should be roughly $10.00 per square foot, which means $4,000 to $5,000 per department worker.

Annual cost of operation is likely to be in the neighborhood of the same figure, i.e., $4,000 to $5,000 per worker, of which about 60% is represented by salaries, 25% by supplies and 15% by "burden."

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[3] A problem of fundamental character, calculated to revolutionize the industry or originate an entirely new industry, is not contemplated here. When such a problem does present itself it is likely to be the outgrowth directly or indirectly of research in the pure science.

[4] Personal communication from Dr. S. P. Burke, corroborated in the main by the experience of the organization with which the writer is connected.

The ratio of the number of laboratory workers to the number of those required for office and maintenance work is ordinarily about 3 to 2.

On this basis a group of six laboratory workers, say one senior research man, three associates and two laboratory helpers, would need the services of four other workers, let us say one clerk who knows something of accounting, a stenographer, an office boy and a handy mechanic, or ten workers in all.

The total building and equipment cost ($4,000 to $5,000 per department worker) should thus be $40,000 to $50,000; to be safe, let us say $50,000.

It may be better and cheaper in the long run to erect a building of at least twice the size at first needed and employ the extra space for operations requiring easily movable equipment, in order that the department, which if successful is likely to double itself every few years, may have room into which to expand without becoming scattered to other buildings.

This $50,000 a year research program should make possible the prosecution of work on three or four research problems or on an equal number of important aspects of a problem of major importance.

As already pointed out, the facilities required in small-scale industrial research differ in no essential, whether for buildings, furniture, or apparatus, from those required in pure scientific research, equipment for which has been described in detail elsewhere in this monograph.

Again, as stated, where the two come to a distinct parting of the ways is in industrial development, particularly in process development, in which attempt is made to apply to manufacture the knowledge gained in research.

Unit Process Development Needs

Unit process, or first-stage development, is best conducted in the same building with, or at least conveniently near, the research of which it is an outgrowth.

The sort of equipment required for unit process development naturally varies with the character of the problem in hand. Ordinarily there are required larger units of the type employed in the initial research, but made of a material suited to produc-

tion on a manufacturing scale. In fact, almost any piece of apparatus employed in the research laboratory has its counterpart in the factory, and a small edition of a factory unit is often employed in such first-stage development. The beaker, dish, flask, condenser, funnel or Gooch crucible, absorption bulb, mortar and pestle, steam bath, drying oven, burner or hot plate, muffle or assay furnace, electrolytic apparatus,—all are exemplified in the factory and are obtainable, or may be constructed, in smaller units of the material employed in factory-size units.

In unit process development no attempt is made to connect the various units employed; hence its name. The main purpose of such development is that of throwing light on quality and yield of product. In this, independent units are to be preferred to connected units, since at this early stage frequent variation of process and product represents the regular order of experiment, and flow lines become a frequent source of contamination. Unit process development may be employed to furnish much information on the corrosion of containing vessels, on the temperature and certain other requirements, and on the main points in the process calling for control. Heating such units electrically is commonly recommended as a matter of convenience involving no great expense. If the process under study is similar to that in established use, unit process development may alone be needed. If the process is new or a decided modification of an old process, another step is likely to be required, viz., the semi-works plant, but unit process development may serve in anticipating and avoiding costly mistakes in a semi-works plant, just as the semi-works plant in turn may save much more costly mistakes in a full-scale manufacturing plant. The hundred pound batch lends itself rather better than does the thousand pound or larger batch, to compliance with the oft-quoted injunction: "Commit your blunders on a small scale and make your profits on a large scale."[5]

Housing Unit Process Development Equipment

As a laboratory for such unit process development there is likely to be required suitable space "serviced" with water, drain-

[5] See "Practical Life as a Complement to University Education." (Address of Acceptance of Perkin Medal) by Dr. L. H. Baekeland. *J. Ind. Eng. Chem.* 8, 184 (1916).

age, gas, steam, electric current, compressed air, and vacuum. Since relatively large apparatus is to be employed, ordinary laboratory furniture plainly is not suited. In fact, until it has been definitely determined just what work is to be conducted the space provided may as well be left open, or at most merely divided into rooms of convenient size. Still, the immediate installation of equipment that is certain to be later required may save annoying and expensive delay, since such equipment is likely to be of special construction and long in the making.

A wide aisle between work benches in the research laboratory may afford space for certain equipment which it is desired to have close at hand, but additional space conveniently near, and ample for future expansion, should be reserved against the day of need.

The Semi-Works Plant

For new or greatly modified processes the semi-works plant affords better opportunity than do independent units for a study of costs, flow relations, transporting methods, proper balancing of production conditions, by-product reclamation or disposal, and fire, poison, and nuisance hazards.

Intelligent conduct of unit process development presupposes a study of conditions likely to be encountered in manufacture, but it is even more important that development on a semi-works scale be not undertaken nor equipment selected without a thorough canvass of all factors likely to influence successful manufacture.

No general formula can be given for the design of a semi-works plant except that derived from the fact that it represents an attempt to anticipate full-scale manufacture. When the passage from small-scale to large-scale production involves mainly the multiplication of small units, the task is relatively simple, but when a large manufacturing unit must be built from experience gained with a small one, the problem presents difficulties and hazards which grow as disparity between the size of the experimental unit and that of the proposed manufacturing plant increases. As examples of the former may be cited, certain electrolytic and catalytic processes, while of the latter we have perhaps the majority of other chemical manufacturing processes, of

which the iron and steel industry, with its large furnace equipment, represents an extreme case in point. Nevertheless, a knowledge of underlying principles, a lively imagination, and acquaintance with existing manufacturing practice should make it possible to anticipate in the development stage many difficulties likely to be encountered in manufacture. As a further aid in avoiding costly mistakes when passing from the relatively small to the large scale, those of mathematical bent may be able to make profitable use of the theory of "dimensional analysis" as applied to heat transfer and the flow of liquids and gases.[6]

Housing the Semi-Works Plant

The character and location of the building required for semi-works development plainly depend on the nature of the process being studied. Manufacturing facilities—power, steam, water, drainage, etc.—will be required, but the installation should be so located as to remain conveniently under control of the research staff until all probable manufacturing difficulties have been met and solved, and it may well be retained intact until there is plainly no further need for it as an economical means for straightening out manufacturing difficulties almost certain to arise.[7] Such a semi-works plant being of a temporary character, economy suggests temporary, cheap housing.

The Pilot Plant

The step into manufacture, the goal of the original research, calls for the combined wisdom acquired in research, in development and in related manufacture. In fact, as initial "equipment" for a program of research and development, a clear concept of the relations here involved is indispensable. Fortun-

[6] See "Dimensional Analysis" by T. W. Bridgman (Yale University Press), and "The Mechanical Properties of Fluids—A Collective Work" (Van Nostrand).

Also see chapter on Flow of Fluids and on Flow of Heat in "Principles of Chemical Engineering" by Walker, Lewis and McAdams (McGraw-Hill).

[7] For a practical discussion of the subject of industrial development the reader is again referred to "The Technical Organization, Its Development and Administration," by Weiss and Downs, under the heading, Experimental Plant Laboratories, pp. 78-86.

ately the literature affords a broad discussion of the subject[8] though perhaps too little emphasis has been placed on the importance of carrying development well into production. The semi-works plant cannot safely be employed to solve all of the problems of production, and the work of development cannot be considered complete until modification of equipment or adjustment of process is no longer the order of the day, nor indeed until at least a promising market is assured. Even when a large market is already waiting, there is apt to be economy of time and money in limiting initial plant construction to one operating unit, or, if these are small, to one group of units. Further construction may wait on information gained through the operation of this tentative installation, aptly called a pilot plant,[9] the experimental operation of which represents the last stage of process development, and should be under the control of a member of the research staff. But, experiment ended, the pilot plant is the natural meeting ground of the research man, interested in experiment, and the production man, interested in uninterrupted, economical manufacture.[10]

Transfer to full-scale production may be a matter of no great difficulty in the case of a minor modification of an existing process, but when the change is radical or when an entirely new industry is in the making, the training of a production force becomes an important part of last-stage development. In any case the research man must cooperate freely and remain available for consultation long after the process has been transferred to commercial production.

The pilot plant may be located on the site of the proposed production plant, but development departments of established industries may find it profitable to maintain close at hand stand-

[8] "The Making of a Chemical," by Lewis and King (John Wiley).

Of interest in this connection are the chapter on Materials and Construction by Percy E. Barbour and that on the Theory of Plant Location and Design by Henry H. Buckmann, both in Liddell's "Handbook of Chemical Engineering" (McGraw-Hill).

[9] See "Financing Chemical Developments," by J. M. Weiss, *Chemical Markets*, Vol. XXIV, No. 2 (January), 1929 pp. 161-5.

[10] The research man may wish to follow his developed project into production and remain with it. There is plenty of favorable precedent for it. Interest and native capacity should govern. But as a method of introducing innovation into the factory, it is not to be recommended. It is better that the man who is to take over production come to the common ground of the final development plant, where experiment causes no confusion and where pointing out a new and better way does not imply criticism of the established order.

ard manufacturing equipment suited, with modification, to experimental production.

Something Concrete

As a concise embodiment of the principles herein set forth the writer fortunately is able to present a brief description with an outline of the plans of a building to house more adequately the department of industrial research of a chemical industry, which department had a beginning in the tentative fashion recommended above. As a result of such conservative beginning, the director of research had ample opportunity to study his industry's needs, in addition to which he profited by a close study of the general problem of laboratory construction and equipment and drew ideas from many quarters. The building described while larger than would be required by our small, hypothetical research group is not as large as would be required by some of our older research organizations, and therefore is likely to come nearer than either to representing the average need. Furthermore it has recently been brought to completion, so that data covering the details of its construction are neither out of date nor out of mind. It should be noted that this building is to be devoted entirely to research and development and, being far removed from any plant of the industry that it serves, is self-contained to an unusual degree. Outline of the floor plan is shown in Figure 104. Following is a description of its general provisions:[11]

Site

The laboratory is situated on a five acre tract near Elizabeth, New Jersey, on the Pennsylvania Railroad. This site was selected primarily for the following reasons:

A. Propinquity of desirable residential facilities for the personnel.

B. The presence of adequate machine and foundry facilities for service beyond the scope of the laboratory equipment.

[11] Furnished to the writer by its designer, Dr. S. P. Burke, Research Director of Combustion Utilities Corporation, subsidiary of Henry L. Doherty Company, New York City.

Fig. 104. Research Laboratory, Combustion Utilities Corp., Linden, N. J.

C. The presence of a "labor market"—since in this case the laboratory is not part of a "works."
D. Excellent freight and transportation facilities.
E. The advantages of the library and educational facilities of the metropolitan district.
F. Absence of embarrassing local ordinances and restrictions on industrial operations.
G. Availability of railroad siding.

General Construction

The main laboratory building is one story, of brick and steel construction, 50 ft. x 220 ft. A multi-story building would prove less economical in this case, for the heavier construction and foundation necessary, the cost of stairways, corridors, elevators, etc., much more than counterbalance the extra land cost. In addition the great convenience of carrying out all operations on one floor and the simplicity of the problem of servicing the rooms dictated the choice most emphatically.

The plans provide for further expansion by three wings extending to the rear from each end and from the center of the building. Two additional small buildings of cheaper construction are provided, one for the storage of laboratory samples, chemicals and other supplies; the other for the storage of dangerous materials such as volatile solvents, etc.

A five-foot corridor runs down the entire length of the main building. The front of the building is given over to administration offices, library and small laboratories. The standard size of the last named is 11 x 18 ft. The rear of the building comprises larger laboratories, special-purpose laboratories, chemical and apparatus stores, heating plant, and meter room. A small wing, 20 ft. x 45 ft. in the rear center provides a well lighted machine shop desirably located. The larger laboratories are 24 ft. deep and about 22 ft. wide. The partitions are of 4 in. cinder concrete block, thus making the entire building, except for the furniture, of fire-resisting construction. It is interesting to note that these partitions are no more expensive than light semi-permanent wood partitions. They are scarcely less "flexible" and have the advantages of being more soundproof and serving as a

support for wall apparatus. The requirement of great internal "flexibility" in an industrial research laboratory is usually over-emphasized. Properly designed and adequately serviced laboratory rooms are excellently adapted to the solution of the great majority of problems.

Especial consideration has been given to lighting. "Artificial day-light" fixtures are provided. The total window area is 60% of the exterior wall area. The type of window adopted gives special ventilation facilities at top and bottom and is so constructed as to provide ready egress from the rooms. In this way the desirable provision that two exits be provided for each laboratory has been fulfilled.

The roof of the building is of gypsum block supported on steel purlins. It is of interest to note that an increased initial cost of several thousand dollars as compared with an alternative roof construction of equal utility results in this case in a yearly saving in fire and occupational insurance of 20% of the increased cost.

Service

Each laboratory room is provided with hot and cold water, compressed air and gas. A small boiler supplies steam at 125 lbs. to the larger laboratories. Each room is also serviced with 110 volt, A. C., single phase current for bench service and 220 volt, A. C., 3 phase current for power purposes. The capacity of the latter circuit is 150 amperes and the wiring is such that this maximum load is available in every room. In addition a portable motor-generator set mounted on wheels provides direct current wherever required. The service lines and pipes are carried completely around the laboratory rooms.

All the main pipes and electric lines are carried overhead through the central corridor, suitable taps being provided to feed the individual rooms. Thus the service facilities are extremely flexible and independent. Troubles are readily detectable and readily repaired. Cut-off valves and switches are conveniently located outside each laboratory room in case of local fires or other danger. All service lines enter the building via the meter room where meters and distribution panels are located. Electricity is purchased at power rates and transformers located in the meter room provide lower

voltages and single phase circuits. The economies thus effected more than justify the transformer investment.

Each laboratory is provided with a hood for obnoxious or dangerous work—each hood being vented directly through the roof with a motor-driven blower. Desks are also placed in each laboratory for report writing, entering data, etc. Separate offices are provided for each of the divisional chiefs.

Fig. 105. Main Corridor with Service Pipes.

The research rooms are provided with benches of the "wall" type, thus allowing maximum floor space in center of room for setting up special equipment, apparatus or movable tables, etc.

Stock Room

A centrally located stock room is maintained in which a limited and selected line of stock materials (chemicals, glassware, instruments and mechanical supplies) is systematically filed.

Fig. 106. Small Laboratory.

Library

The library, constituting as it does the heart of the research laboratory, is centrally located and protected as much as possible from noisy or obnoxious operations. All reports, data books, and informational files are located here and a specially constructed fireproof vault is provided for original data, drawings, reports, etc. In addition the library includes a museum in order to illustrate in a physical manner the progress, accomplishments or status of the research work. Owing to the proximity of the libraries of the metropolitan district, the number of volumes and magazines that must be permanently housed is less than would otherwise be the case.

Experimental Plant Operations

The main building just described is designed to house research and small-scale operations. It should be noted that a monitor equipped with a travelling hoist is provided to give increased head room over a limited area for carrying on operations requiring unusually tall apparatus. Larger operations of an experimental-plant nature or unit process character will be carried on in buildings of cheaper construction

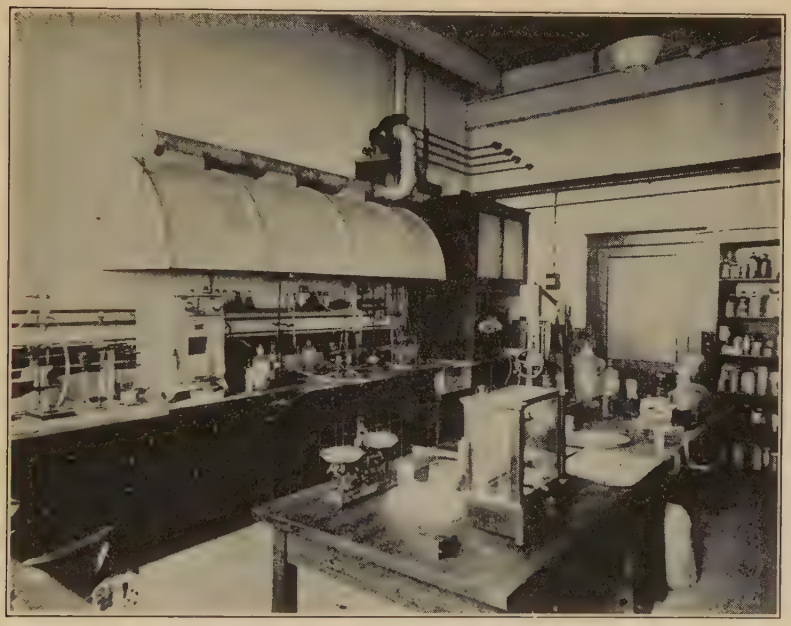

Fig. 107. Larger Chemical Laboratory.

located in the rear of the main laboratory building, for which the site provides ample space and desirable facilities.

The accompanying interior views show:

Fig. 105. Portion of the main corridor with service pipes on ceiling.

Fig. 106. One side of small laboratory.

Fig. 107. Side and middle of larger chemical laboratory.

Fig. 108. One of the development laboratories, containing unit process equipment.

While there are those who will not find a one-story building feasible, because of the high cost of land or the scarcity of that available as a site, still with modifications to fit individual requirements, the plans outlined above are of very general application.

Another Example

Industrial chemical research is by no means confined in its application to the industries called chemical. The electrical and

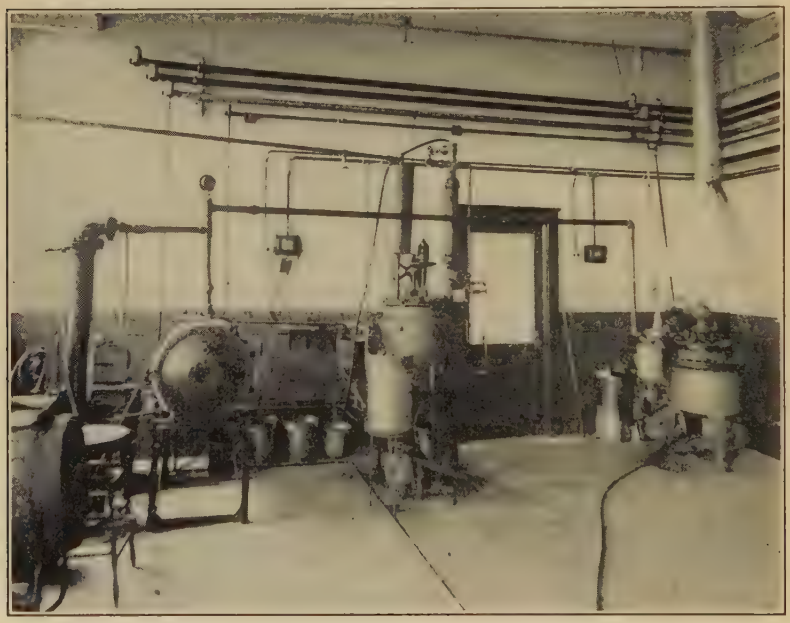

Fig. 108. Development Laboratory with Unit Process Equipment.

mechanical industries have their research problems which are chemical. In fact, to the extent that they produce their own materials of construction, they are also chemical industries. Following is a brief description of the equipment of the chemical laboratories of a large manufacturer of electrical appliances.[12] Here, housed in one building, are laboratories for research, for small-scale development and for analytical control of raw materials, processes and products.

[12] Furnished to the writer by Mr. G. S. Rutherford, Assistant Superintendent of Manufacturing Development, The Western Electric Company, Chicago, Ill.

1. General Purpose

The laboratories described in this outline provide one comparatively large room for routine chemical analysis relating to the inspection of raw materials and process control, a medium-sized room for investigations of methods of analysis and health hazards, and seven smaller laboratories for preliminary small-scale development work on paints, varnishes, japans, lacquers, rubber, plastic moulding compounds, insulating papers, textiles, white metals, ferrous alloys and electroplating. Space for the development of processes requiring more head-room and larger apparatus has been partitioned off from the first floor of some of the operating departments. Development studies are also carried on in unit installations in the same buildings with other manufacturing operations. Other development work relating to the mechanical and electrical side of the telephone industry is conducted in a separate group of laboratories.

2. Site

The site was determined by the availability of space, the building selected being well located with respect to the cable manufacturing operations, but further removed from the main group of buildings where the telephone apparatus is manufactured. The building is a part of the cable plant group with main entrance direct from the street but also directly accessible from the plant.

3. Building

The building is of brick and steel construction, 151 feet long from east to west by 52 feet wide. The laboratories occupy the entire third floor which is reached by stairways at each end of the building. The windows are arranged in bays 18 ft. 9 in. long, each bay having a group of three steel window sashes with wire glass except along the north (street) side of the building where clear glass is used in sliding wooden sashes in similar groups of three. The window area amounts to about 38 per cent of the exterior wall area, or 24 per cent of the floor area. The floors are of hard wood laid over concrete. Steel and glass partitions divide the space into one office, 17

ft. x 24 ft.; one large analytical laboratory 21 ft. x 55 ft. (Fig. 109); one medium-sized methods laboratory, 21 ft. x 37 ft.; seven smaller special-purpose laboratories, 18 ft. x 21 ft. (Fig. 110); one balance-room, 8 ft. x 21 ft.; men's toilet, 17 ft. x 19 ft.; and one stockroom, 8 ft. x 21 ft. A six-foot corridor extends the entire length of the building from the office at the east end. Steel fire doors communicate from the corridor to the stairways, and wooden doors with glass panels open into the corridor from the laboratories. In order to provide the desirable feature of two exits, a second door is provided in the partitions between rooms. The whole layout is shown in the accompanying plan (Fig. 111).

Fig. 109. Analytical Laboratory, Western Electric Co.

4. Chemical Laboratory Tables

(*a*) The analytical laboratory tables are arranged in double units extending from the north wall of the two large laboratories into the room, with additional single tables along the partitions at the ends of the room except

where this space is occupied by apparatus cabinets and special tables. The chemical tables in the smaller special-purpose laboratories are arranged around the walls with large tables in the middle of each room as needed. The chemical tables are of oak construction with 1¼ in. alberene stone tops. The height from the floor to the top of the alberene slab is 36 inches. Below the slab are drawers and cupboards for the storage of apparatus in daily use, and above are two acid-proof hardwood shelves 8 in. wide for reagents.

Fig. 110. Special-Purpose Laboratory, Western Electric Co.

(*b*) The double tables measure 15 ft. x 5 ft. with working space on each side for two chemists. Alberene sinks 17½ in. x 21 in. are built in midway between the working spaces on each side. The single units are 15 ft. x 2 ft. 6 in. with space for two chemists and a 17½ in. x 21 in. sink between the two positions. At each position a slide writing board is provided. This furnishes a support 15 in. deep by 18 in. wide for note-book, and it slides out

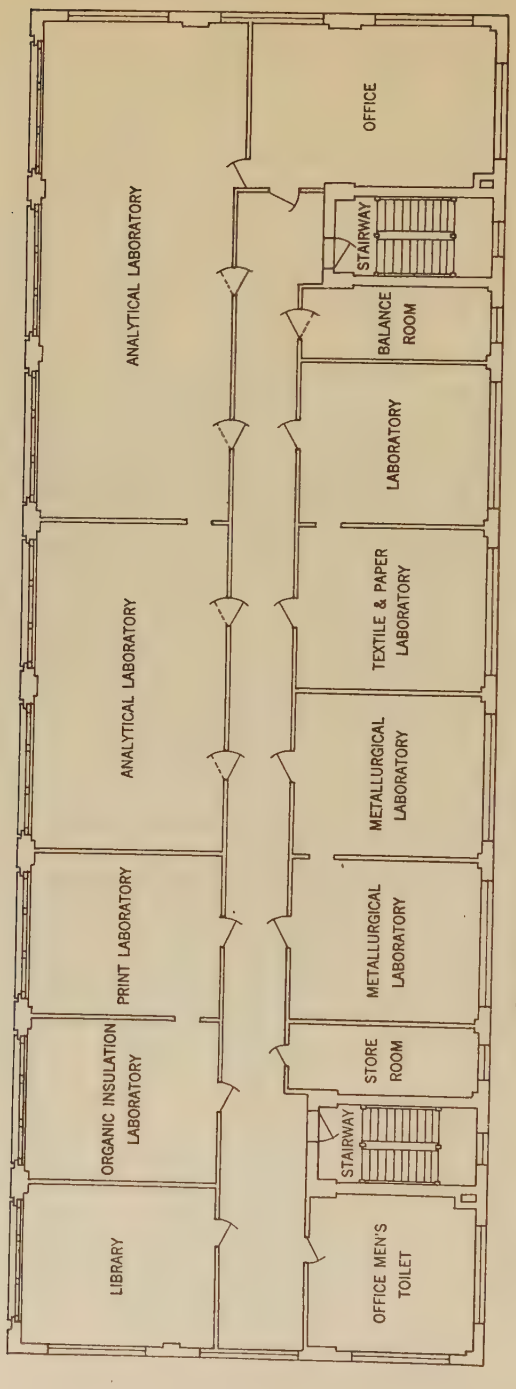

Fig. 111. Chemical Laboratory Layout, Western Electric Co.

of the way beneath the stone top when not in use. Center tables in the smaller rooms vary in dimensions according to requirements; one measuring 2½ ft. x 8 ft. with open space beneath has been found useful. In some instances the space under these tables has been utilized for storage by building in special cabinets in removable units. The tops of center tables are generally of hard wood instead of alberene. The tables can be removed if the space is needed for erecting large apparatus. The working space between chemical tables is 48 in. in nearly all cases.

5. Hoods

All hoods are constructed of alberene stone and wire glass. There are two sizes, one a double unit 6 ft. 10 in. long by 5 ft. wide corresponding to the width of the double chemical benches; the other a single unit, 6 ft. long by 2 ft. 6 in. wide. The double hoods actually comprise two separate hoods built back to back and mounted on one end of alternate double chemical benches in the two larger laboratories. When so mounted, the double table has working space for only two chemists, but between two such hoods, a double-width table is installed with working space for four. Each side of a double hood is therefore conveniently accessible to three chemists. The single hoods are installed against the partitions. The face of each hood is equipped with sliding wooden sash fitted with wire-glass and counter-balances suspended by bronze chains operating over a bronze pulley within the alberene casing and not exposed to the fumes within the hoods. Beneath the stone slab, the top of which is 36 in. above the floor as in the work tables, storage space for samples and chemicals is provided in the form of Fales Sections 11⅝ in. wide by 19½ in. deep mounted on rollers to allow drawing out. Each section is divided from front to back with three adjustable shelves on each side of the partition. The single hoods are practically identical with one section of the double units but 10 inches shorter. All hoods are vented direct through the roof with electrically driven multi-vane blowers.

6. Service Connections

(*a*) Service mains from the factory supply lines are suspended from the ceiling of the floor below. Connection is made through the laboratory floor to the service piping on each chemical table. This includes air, vacuum, gas, hot and cold water, and 110 volt alternating current. The five lines of pipe are suspended in a vertical plane beneath the lower reagent shelf. The first line is ½ in. conduit provided with two electric outlets for each working position and No. 14 wire to the floor. The second line is a ⅜ in. vacuum pipe provided with two single outlets. The third line is a ⅜ in. air pipe also equipped with two outlets. The fourth line is a gas pipe of similar size and outlets; and the bottom line is ½ in. water pipe equipped with two single outlets for rubber tubing. All piping is provided with shut-off valves at the floor. The hot and cold water is also piped to faucets at each sink. A special faucet lined with block-tin and provided with a silver plug for distilled water is installed at each sink and connected to the steam still by block-tin tubing.

(*b*) Each hood is equipped with air, vacuum, gas, water, steam and electrical services. In addition to these a special steam bath is built into the alberene so that the porcelain rings are flush with the top of the slab.

(*c*) Sinks are provided with Duriron traps and plumbing connections to the drain.

(*d*) Special electrical service required for electroplating experiments and electrolytic analysis is obtained from the usual motor-generator sets.

7. Special Equipment

Equipment of a special nature affecting the layout of the laboratories includes such items as a three-roll mill, a Pony mixer, spray-coating apparatus, and a drying cabinet in the paint laboratory; pedestal vacuum dryer in the organic insulation laboratory; thermostat bath and fade-ometer in the analytical laboratories; tensile testers, and constant humidity tank in the textile and paper laboratory; and several gas and electric muffle and crucible furnaces in the metallurgical laboratory installed under a

metal hood vented direct through the roof with an electric motor-driven multi-vane fan.

8. Emergency Showers

Midway between the two wire glass lift-doors of each hood, an emergency shower with a quick-acting valve is installed. The standpipe above the valve is perforated to allow the flow of water directly against the head and shoulders, and a large sprinkler or shower-head above insures prompt deluging with water when needed. The shower-head is an inverted cast-iron ring gas-burner. Although not often called into use, these showers have demonstrated their worth in the prompt first-aid treatment of acid burns.

9. Balance Room

The balance room is located across the corridor from the routine analytical laboratory and is accordingly convenient for the greatest number. It also contains balances used by chemists from the other development laboratories. The room is 21 ft. long by 8 ft. wide with a shelf for balances along one side against a brick wall and a table along the other side against the steel partition. The shelf and table are 38 in. high and both have cabinets of wood and glass to enclose the balance cases. Each cabinet is equipped with a clear glass wood-sash lift-door. There are seven balances on each side of the room. Entrance is by a double-hinged door swinging both ways.

10. Library

The Chemical Reference Library, which formerly occupied the northeast corner room, has been consolidated with the Works Library, leaving this space available for expansion of the laboratories. About 150 duplicate volumes including the texts most often used have been placed in sectional bookcases in the laboratory office. The separation of the main reference library from the laboratories has been arranged to suit the convenience of the majority.

11. Lighting

The rooms are lighted by means of 150 watt frosted lamps in glass reflectors suspended about 2 feet below

the ceiling and well out of reach from the floor, thus avoiding the tendency to connect unsuitable apparatus with the lighting circuit. The lamps are spaced about 8 feet apart. Special portable daylight lamps are used for titration purposes. Good daylight illumination is insured by the large window area, the maximum depth of room of only 21 feet, and the white painted ceilings and walls above the 6-ft. dark green wainscoting.

12. Heating

Heating is by direct radiation from water radiators mounted on the wall beneath the windows.

13. Personnel

The laboratory facilities are apportioned among several divisions of the Development Branch, but they are not used continuously by all employees of these groups. The average number of laboratory workers is about forty, and the floor area per worker is therefore less than two hundred square feet. Although this space per worker is less than that usually recommended, it is reasonably satisfactory since the work requiring larger apparatus is generally conducted in other parts of the plant. The desk space in the office is assigned to the Development Engineer in charge of the Chemical Laboratories Division, his department heads, section heads, stenographer and clerk.

Of special interest and value in this connection are the following comments by one who was largely responsible for the original plans and later for conduct of the department making use of the equipment just described.[13]

> Total floor space was determined by study of probable laboratory facilities required for initial development work on problems in hand and definitely anticipated. To this was added the definite space requirements for service laboratories with conservative additions for growth of service.

[13] Personal communication from Mr. F. W. Willard, Personnel Director, Western Electric Company, New York City, formerly Assistant Superintendent of Manufacturing Development at the Hawthorne Plant, Chicago, Ill.

New buildings were not considered because reasonably suitable space in existing buildings was made available.

The laboratory for analytical service (material and process inspection) was separated from the analytical laboratory serving development and research groups.

Laboratories for specific research were provided on the basis of main groups of problems in hand and forecast, such as Metallurgical, Electrochemical, Plastics, Textiles and Paper, Paints, Varnishes, Lacquers, etc.

A separate permanent group of laboratories for specific advanced development of projects of some magnitude was provided simultaneously elsewhere.

Adequate office and library facilities were provided but a much-needed conference room was not foreseen. This I think was a distinct error.

The special laboratories for development and research were not provided with special equipment except where such equipment was known to be of common utility for the work in hand and projected.

From the beginning it was planned to have each development project bear the cost of any equipment specific to itself. This was a wise provision. If it had not been done the laboratories would have been cluttered with special-purpose equipment greatly increasing the original capital expenditure.

The individual special laboratories were constructed larger than is good practice because of the structural characteristics of the building occupied.

A separate balance room was provided primarily as a space-saver. I do not approve the practice.

Ventilating of hoods was conditioned by the structural characteristics of the building and though satisfactory was expensive in first cost. I prefer the simpler individual exhausts to the exterior.

Stone hood walls are expensive in first cost but believed to be ultimately more economical.

Electrical power service from the ceiling, but gas, air, steam and exhaust from below, are good practice.

The plumbing is practically all open and accessible. Duriron drains were used generally.

Central distilled water serviced to the benches through tin pipes with silver valves is somewhat of a luxury. The convenience is probably not worth the cost.

Easily-operated emergency showers on each hood are justifiable. At least one chemist in these laboratories was saved from permanent disablement and probably death by one of these.

The fancy steel partitions used were also determined by the character of the problem of constructing laboratories in an existing building. Hollow tile is cheaper and better.

This group of laboratories was not provided for use under any circumstances for second-stage development.

Though good north lighting with large window areas existed the location gives so many dark daytime hours that daylight lamps were provided.

The plans do not represent an ideal but an approach conditioned by the building and the kind of work to be done. They have so far met the essential needs. I suspect that all laboratories built and to be built will go up on about the same basis.

The conditions, I repeat:

A ready-made building.

A large number of widely differentiated projects for development.

Only simple equipment common to all problems.

Random Points of Possible Interest

The department with which the writer is connected occupies buildings that were formerly used for manufacturing purposes by the Corporation it serves.[14] For reasons of policy an additional building required for research was constructed of factory type also. The problem has been that of adapting this manufacturing plant to the requirements of industrial research.

This has been done with fair success by providing ready means of intercommunication between research and advanced development, which are housed for the most part in separate buildings, and between these and the office building; also by setting up special research facilities near development

[14]Located in Bloomfield, New Jersey.

equipment whenever the latter becomes too extensive to be housed in the main research building.

Overhead Passageways

Improved intercommunication between research and development was effected by connecting with enclosed overhead passageways the second floor of the main research building and that of the main development building (both two-story) through the corridor of the second floor of the intervening office building (also two-story and having a driveway on either side). This plan, which at first was considered of debatable utility, has been a source of great convenience with little disturbance to the library and offices, in closed rooms on either side.

Research Equipment

The space devoted to research, unlike that of the research buildings earlier described, is not partitioned into rooms, but

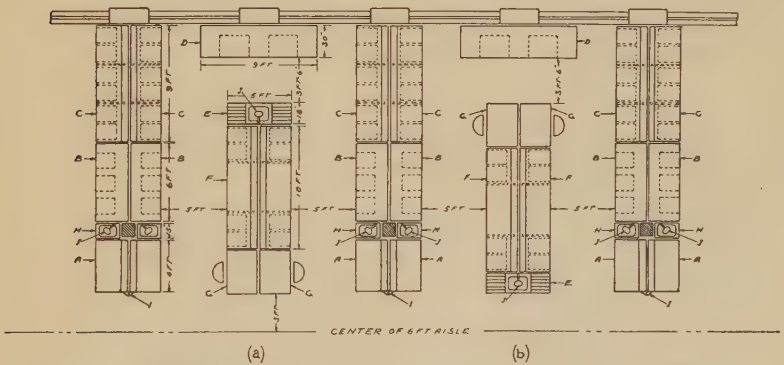

Fig. 112. Research Laboratory Layout, Bakelite Corp., Bloomfield, N. J.

some measure of privacy is afforded by the arrangement of the work tables and hoods. A grouping now in use and found convenient is shown in Figure 112, (a). An alternate arrangement (b) affords greater privacy for desk work.[15]

Table Tops

Asbestos-cement board has long been used in thin sheets as a covering for laboratory table tops. Its use, alone, in

[15] The only advantages of such a stall system as compared with rooms are greater flexibility in apportionment of space and a lower construction cost. For research, in which freedom from interruption is of first importance, rooms are without doubt to be preferred.

thick slabs is less usual. It may therefore be worthy of mention that slabs of this material (in this case, Transite), one inch thick, have given good service in the laboratory under discussion. That is, they have not warped, cracked, nor charred under heat (the main characteristics here sought) though they tend to become unsightly. Greater rigidity, as may be required for long, unsupported spans, can be obtained by using 1¼ in. or 1½ in. slabs. The cost is comparable with that of hardwood and soapstone.[16]

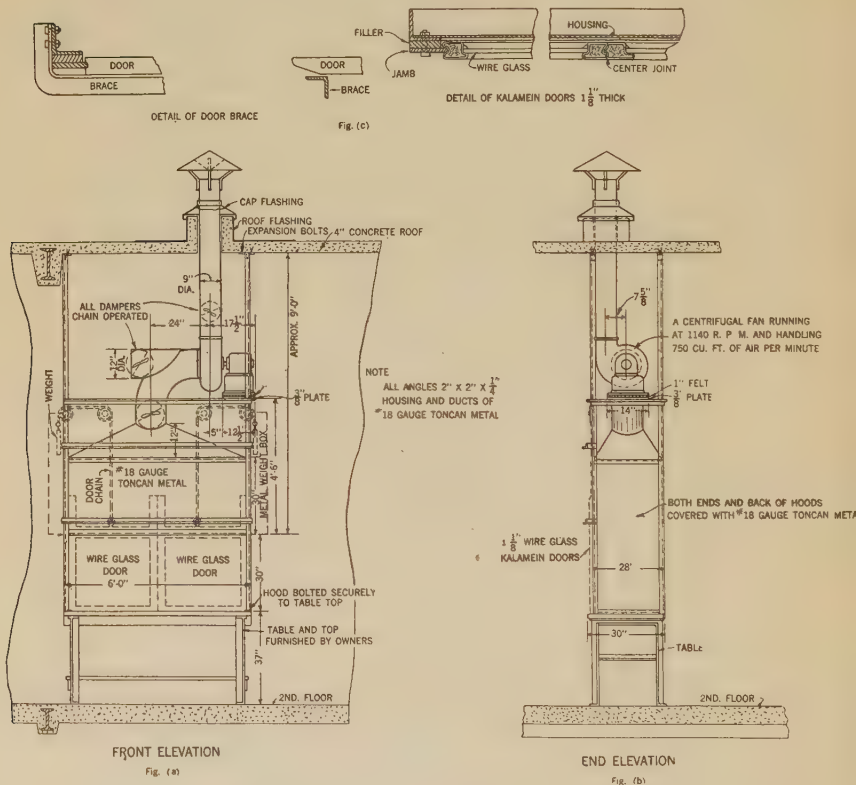

Fig. 113. Hood Construction, Bakelite Corp., Bloomfield, N. J.

Galvanized Steel Hoods

In the absence of acid fumes, galvanized steel is serviceable and is cheaper than soapstone as a material for hood

[16] See "Laboratory Table Top Materials." *Industrial and Engineering Chemistry,* Volume 15, pages 569-70.

construction. The details of such a galvanized steel hood are given in Figure 113, (a), (b), and (c). Operation is quiet and effective. When the hood doors are wide open, air enters the hood at a velocity of about 50 (linear) feet per minute. The doors need be closed only as a precautionary measure when handling very noxious or poisonous fumes, or in case difficulty is experienced in heating the building when they are open. Baffles may be employed giving increased velocity at back of hood table and top of front opening. They are omitted here to afford head room for long reflux condensers. Steel bench legs provide a substantial and economical base for the 3 in. hard pine frame work (not shown) of the table top, which is surmounted by 1 in. Transite. As with handling air generally, all duct bends should be rounded or employ no angle sharper than 135°. The only disappointing results experienced in the use of these hoods were traced in each case to faulty installation, by which the fan was caused to run backward, a condition which may escape notice since the effect is lowered efficiency more often than reversal of direction in the flow of air.

Electric Outlets

Of possible interest, though by no means unique, is the three-wire system, delivering either 110 volt or 220 volt alternating current from all sockets, danger of confusion being averted through the use on all apparatus of standard "polarized" plugs wired to receive the voltage required and that only.

Fire Protection

In addition to the regulation sprinkler system, personal hazard from fire is reduced by (1) providing an overhead water shower with quick-opening valve within easy reach alongside of each hood, over the sink at the end of each middle work table, and, as a special measure of safety, at each exit from the building; (2) all-wool blankets on rollers[17] at the end of each double line of side tables and (3) "foaming" and carbon tetrachloride extinguishers at easily accessible points. One 30 gallon "foaming" extinguisher mounted on

[17] See description of special fire blanket roller in "The Technical Organization, Its Development and Administration," by Weiss and Downs, p. 135.

wheels is maintained in readiness for the fire that may resist milder measures.

Stores

As with the individual laboratory units employed in research, so with the dispensing "room," the space employed is set off by its own equipment. In this latter case sectional steel shelving with sheet steel backing provides both storage and isolation for laboratory supplies. A feature of convenience is shelving erected on the outside of the same supporting frame work. Here are maintained supplies frequently required and not regularly checked in and out of stock. Dispensing stocks are replenished from central stores, maintained, along with a receiving station, at a location near the plant entrance.

Development

First-stage development equipment is set up either in the research laboratory units, or, in the case of relatively large equipment, in space conveniently near.

In furtherance of the policy of carrying last-stage development well into production (with sales) before transfer to the manufacturing department, connected units regularly employed in manufacturing are maintained on the first floor of the main development building (former factory building, 200 ft. by 50 ft.) and in a building of concrete and tile (183 ft. by 42 ft.) constructed for the purpose. In each of these buildings are maintained also limited facilities for research and for small-scale development.

Central Offices

Offices for the director of research and his associates, the accounting and purchasing departments, and the stenographic force are located in a two-story brick building (50 ft. by 40 ft.) constructed for the purpose and connected with the research and development buildings by enclosed overhead passageways on either side, as described above.

The Library

The library occupies a space 31 ft. by 21 ft. on the second floor of the office building. Attempt is made to limit the books received to those of value for general reference, those

of direct and related bearing on the industry, and a limited number of bound files of scientific and technical journals. No attempt is made to maintain complete files of all of the scientific publications regularly received. Where very occasional use only is anticipated, advantage is taken rather of extensive library facilities to be found in the vicinity. Two reading tables, a journal rack, sectional book cases as needed and, not least, a librarian who is also a chemist by training, complete the "equipment" provided.[18]

Other Service Divisions

The Physical Laboratory equipped for the determination of physical and electrical constants and for research on the methods employed; the Experimental Moulding Room with its hydraulic presses and gas-fired boiler to provide steam of higher pressure for the platens and moulds; the Machine Shop where the steel moulds and physical apparatus are made and which is headquarters for the work of plant maintenance—these, separated by partitions, occupy each about a third of the first floor of the research building. They are in no way unusual but too important to leave out of the picture.

Six scattered smaller buildings used for storage and for development involving relatively greater fire hazard complete the plant now employed, with a fair measure of convenience and economy for research and development. Of scarcely less importance to continued prosecution of the work is a parcel of unoccupied land, part of which is certain to be needed to provide space for added buildings.

Analytical Laboratories

As originally constituted, some measure of industrial research was conducted in and around the laboratory called analytic, but with greater emphasis on research has come its separation from the work of factory control. However, analytical control of processes and of the quality of raw materials and finished products continues indispensable to proper conduct of chemical manufacture.

A large factory ordinarily has a central analytical laboratory

[18] See "Symposium on Library Service in Industrial Laboratories," *Industrial and Engineering Chemistry,* Volume 11 (1919), pages 578-89.

given to control of processes and of the quality of raw materials and finished products, together with small branch testing stations located wherever needed for especially prompt process control.

The necessary basic equipment differs in no essential from that required for research. One of the laboratory units shown in Figure 112 and, as may be recalled, the large laboratory (Figure 109) described in the second set of plans (Figure 111), given earlier in this chapter, are employed for analysis.

Apparatus to be emphasized by the installation of large units or a large battery of standard units—for digestion, extraction, distillation, desiccation, ignition—is well covered by the literature, scientific and commercial, to which the reader is referred.

The equipment of small laboratories in the plant for the control of processes that are characterized by rapidly progressive change is ordinarily as simple as the tests themselves are rapid and varies, of course, with the process to be controlled.

Conclusion

Whether our industrial chemical laboratory be constructed and equipped for research, for development, or for analytical control, little more than the underlying principles involved and a few well-chosen examples of their application would appear to be required by one thoroughly acquainted with the industry to be served and with the science that underlies it.

The laboratories selected for description in this chapter are of medium size, and represent three quite different industries and as many different housing problems. However, the literature affords descriptions of a number of other laboratories each with its own problems of construction, equipment, and arrangement. Some of them are very large and have developed correspondingly large, well organized library and other facilities. The reader interested in further example is referred to the literature, important reference to which is given below.

Calling to mind the main points—

The chemical laboratory, whether for analysis or for research, scientific or technical, has been practically standardized in its basic equipment requirements.

It is the industrial exploitation of research that calls for special

equipment, financial as well as physical, and gives special point to separate discussion of the construction and equipment of industrial chemical laboratories.

Economy suggests that as a beginning, equipment for research be limited and housing tentative. Provision of permanent facilities may wait on a justifying measure of initial success, and enjoy the benefit of the experience thus gained. As further aid to wise expenditure there are available (and given herein) certain pertinent facts gleaned from the experience of established industrial research organizations, touching the inter-relations of cost, floor space, and personnel.

Descriptions of well-planned industrial chemical laboratories, herein given in some detail, though planned for very unlike industries, show marked basic similarity.

The variety of special equipment required by different industries is too great for discussion in one chapter. For description of such special equipment the reader is referred to the literature of industrial and engineering chemistry.

Additional reference to the general subject follows:

W. A. Hamor, "Description of the Building of the Mellon Institute." *Jour. Ind. and Eng. Chem.* (1915), pp. 333-343. (Illustrated.)

D. Jenkins, "The New Jersey Zinc Co.'s Franklin Laboratory." *Am. Inst. Min. Engrs. Bul. No. 128* (1917), pp. 1181-5. (Illustrated.)

A. P. M. Flemming, "Industrial Research in the United States of America." *Dept. Sci. & Ind. Research,* London, 1917. Detailed account of the chief American research laboratories. (Illustrated.)

A. P. M. Flemming, "Planning a Works Research Organization." *Inst. Elect. Engrs. Jour.,* V. 57 (1919, pp. 153-70, 170-92, 386-406). A comprehensive discussion of laboratory planning and construction. (Illustrated.)

A series of papers on "Industrial Research Laboratories." *Sibley Jour. of Eng.,* V. 32 (1918);

F. K. Richtmeyer—Introduction, p. 80;

P. G. Nutting—1. "Research and the Industries," pp. 81-84;

H. R. Hosmer—2. "The Research Laboratory of the General Electric Co.," pp. 98-103;

E. P. Hyde—3, "The Aims, the Organization and the Work of the N. E. L. A. Research Laboratory," pp. 123-6.

C. E. K. Mees, "Planning a Research Laboratory for an Industry." *Ind. & Eng. Chem.,* V. 10 (1918), pp. 476-80.

A. D. Little and H. E. Howe, "The Organization and Conduct of an Industrial Laboratory." (Gives floor plans and description of building and equipment.) *Proc. A. S. M. E.* for 1919, pp. 77-81. Also, "Modern Laboratory for Industrial Research;" Arthur D. Little, Inc. (Illustrated.) *Chem. & Met. Eng.,* V. 19 (1918), pp. 100-1.

Emerson P. Poste, "Enameled Products Research Laboratory." *Chem. & Met. Eng.,* V. 25 (1921), pp. 974-5.

"The Organization of Industrial Scientific Research," by C. E. K. Mees, referred to in the text, contains many references to the laboratory of the Eastman Kodak Co. and has a chapter on "The Building and Equipment of the Laboratory," in which is given a description of the Westinghouse laboratory building at Pittsburgh. The book also contains a very complete bibliography down to 1919.

"The Technical Organization, Its Development and Administration," by Weiss and Downs, also referred to in the text, contains references to the organization and equipment of the laboratory of The Barrett Co. and has a chapter on "Layout and Housekeeping" that should prove helpful.

The *Journal of Industrial and Engineering Chemistry* for March, 1920 (V. 12), pp. 295-6, contains a list of references to descriptions of Chemical and Engineering Laboratories.

"Chemische Laboratorien," by Prof. A. Behre, pp. X-113. Leipzig; Akedemishe Verlagsgesellschaft, m.b.H., 1928, treats in great detail of the construction and equipment of the technical chemical laboratory as well as the university laboratory.

As further sources of information the reader may well consult the National Research Council's Research Information Service (Washington) and its Division of Engineering and Industrial Research (New York). Its Bulletin No. 60 gives a list of the Industrial Research Laboratories of the United States in 1927.

CHAPTER XX

LABORATORIES FOR BIOCHEMICAL TEACHING

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It requires but a cursory survey of that section of *"Chemical Abstracts"* devoted to biological chemistry to impress one with the vast scope of this branch of our science. Biochemistry may be said to be a transition between chemistry in its varied phases, such as organic, analytical, physical, etc., and biology, which includes physiology, pathology, bacteriology, zoology, botany, etc. It is thus evident that the construction and equipment of a biochemical laboratory is largely governed by the special services which are expected of it.

There are three large groups of institutions of which biochemical laboratories form a part, viz., the medical college or university, the hospital and the research organization, stated in the order of increasing specialization. Because of its affiliation with many other branches of chemistry there are numerous features of a biochemical laboratory which may be more fully discussed elsewhere in this volume. The well-equipped biochemical laboratory, in addition to its own distinctive characteristics, should partake somewhat of the nature of the organic laboratory, the analytical laboratory, the bacteriological laboratory, the physico-chemical laboratory, etc.

Types of Equipment. In view of the wide choice of equipment offered by the laboratory supply houses for each of these special types of laboratories, it is impractical in the space available to present them all or to discuss their advantages or disadvantages. For this purpose reference must be made to the catalogues of the various dealers. The purpose of this chapter

will be to point out some of the most important types of equipment to be included in a well-equipped biochemical laboratory, the details of design and selection being left to the individual chemist or architect.

Type of Structure. The lecture room, library, store room, etc., which form a part of the biochemical department, need present no special difference, except as to contents, from the ordinary chemical laboratory. In the medical college or hospital, the amphitheater type of lecture hall is often preferred, although unless special provisions are made for proper ventilation, the atmosphere in the upper levels of such a hall becomes decidedly soporific.

Special Rooms. There are a few additional features of a biochemical laboratory which, while highly desirable, are not particularly characteristic of this type of laboratory and will therefore be dismissed with a few words in the early part of this discussion. Where considerable research work is in prospect there should be provided a glass-blowing department, which should contain the necessary equipment for the use of the oxy-acetylene flame so desirable for work with Pyrex glass. There should also be a shop provided with lathes, drill presses and other machinery for the construction of precision apparatus. Such departments as these are more fully treated in the earlier chapters of this book.

Dark Room. Another desirable addition to the armamentarium of a complete biochemical laboratory is a photographic dark room. The equipment with which this room should be provided depends somewhat on the nature of the work. For hospital work there should be adjoining the dark room a small studio equipped with cameras for photographing patients. The dark room, which incidentally should be painted white to provide maximum reflection, should contain a large sink with a swivel faucet. A useful and protective accessory to the sink is a wooden grid covering its entire bottom. The safe light may be set upright on the shelf above the sink or it may be preferred to use the suspended type of safe light, so that the illumination is directed downward upon the work. A white porcelain or enameled sink offers ample reflection of light.

In addition to the usual complement of tanks, trays, printing outfit, cutter, etc., the dark room should include a photomicro-

graphic camera and also an enlarging camera. The variety of equipment of this description is so great, that reference must be made to a catalogue of photographic supplies in order to obtain a selection suitable for the purpose in hand.

Tables. The teaching laboratory should contain rows of laboratory tables of the "center type," i.e., with tables on each side of a central reagent shelf, below which is constructed a lead-lined or stone trough. The tables may be constructed of wood or preferably of lead-coated sheet steel. The latter material, while slightly more expensive, possesses the advantage of being fireproof. Moreover, the drawers in this type of laboratory table may be constructed on ball bearings, providing maximum ease of opening and closing, and at the same time these drawers never stick or warp. An additional and very significant advantage of steel equipment is that the danger of infestation with roaches is minimized.

Table Tops. Table tops may be constructed of birch treated with chemically resistant "ebony" finish, or soapstone tops may be used. Each type of material has its adherents, although in a teaching laboratory the material which would stand the hardest wear, namely, stone, is to be preferred.

Utilities. Each working space should be equipped with gas, compressed air, vacuum, a water outlet and an electric outlet. A most welcome improvement in the fixtures of a chemical laboratory has been the introduction of chromium-plated plumbing fixtures. These not only add to the appearance of a laboratory, but are desirable because of their acid-resisting qualities.

Lighting. Window exposure in a biochemical laboratory should be toward the north, because light from the north cloudless sky is most desirable for colorimetric or microscopic work. Many workers prefer, however, to avoid the variations in natural light and therefore use special colorimeter lamps equipped with daylight filters, and for microscopic work the small substage lamp is widely used.

Hood Equipment. The biochemical laboratory should be provided with hoods for Kjeldahl digestions or for the evaporation of urine, feces or other biological material. If space is available it is desirable to provide a separate room for this purpose which might contain, in addition to the digestion apparatus, steam baths, etc., in the hoods, and a Kjeldahl distillation rack. This room

might also contain a still for the preparation of distilled water, a hydrogen sulfide generator, an electric muffle furnace, a vacuum oven, a drying oven, an autoclave, a centrifuge, an electric shaking machine, a bank of Soxhlet extraction outfits, and other equipment which it is desirable to keep outside of the general laboratory.

Incubators. An incubator is a necessary piece of equipment in the biochemical as well as the bacteriological laboratory, especially for the study of enzymes. Incubators may be obtained in all sizes ranging from the small chamber used in the doctor's office to the large room forming a part of every well-equipped bacteriological laboratory.

Refrigerator. Facilities should be provided for adequate refrigeration of biological specimens and of reagents which must be preserved in the cold. For this purpose the gas or electric refrigerators are highly suitable.

Balances. Several analytical balances should be distributed at different points around the biochemical teaching laboratory. In order to provide experience in the use of the balance, the ordinary type of instrument should be used, but where a large volume of analytical work is done, e.g., in a research, the new Chainomatic balances with the dumbbell riders, save much valuable time by eliminating the need for all weights below 1 gm.

Special Apparatus Room. Aside from the microscopes and colorimeters, two most important pieces of equipment in the biochemical laboratory, there are many special pieces of equipment which, while they do not find constant or widespread use, are essential in certain types of work, and must be included to complete the story. It is very practical to provide a separate room for apparatus of this kind which may serve the purpose not only of a store room, but also of a special laboratory. Without going into detail, such special equipment may be mentioned as a polariscope, a refractometer, surface tension apparatus, an ultramicroscope, a spectrophotometer, conductivity apparatus, a potentiometer, a bomb calorimeter, a combustion furnace, a supercentrifuge, a Pregl balance and complete microchemical apparatus and a basal metabolism outfit. Each of these items may be obtained in great variety, depending on kind, size, expense, etc. For their complete description, as well as for the description of special glassware and apparatus used in blood chemistry,

urine analysis, and other important phases of biochemistry, the catalogues of the laboratory supply houses must be consulted.

Care of Animals. A most distinctive feature of biochemical work is that performed on animals and hence adequate facilities for maintenance, breeding and operating must be provided. The animals most commonly used in biochemical work are dogs, rats, mice, guinea pigs, rabbits and pigeons.

Many valuable suggestions for the care and maintenance of these animals may be found among the following references:

"Die Operative Technik Des Tierexperimentes," H. F. O. Haberland (Julius Springer, Berlin, 1926).

"Practical Physiological Chemistry," Hawk & Bergein (P. Blakiston's Son & Co., Philadelphia, 1926).

"Breeding and Care of the Albino Rat," Greenman and Duhring (Wistar Institute, Philadelphia, 1923).

"A Text Book of Biological Assays," Pittenger (P. Blakiston's Son & Co., Philadelphia, 1928).

Animal Room. The animal room should be built either on the top floor of the building or preferably in a penthouse. If dogs are kept in considerable numbers, it is highly desirable, from a standpoint of quiet, to have a vivarium apart from the main building. Ordinarily, however, very satisfactory facilities for keeping dogs may be constructed in a penthouse with large kennels opening through the wall into caged areas on the roof, thus giving the dogs ample opportunity for exercise and play.

Rooms in which animals are housed should be constructed with tile or cement floors, the corners of which should be rounded in order to avoid cracks in which insects may breed. These floors also facilitate frequent mopping and scouring, which operations are so essential to the sanitation of the inmates, as well as to the esthetic sensibilities of the workers. It is very satisfactory to construct the floor with a gentle slope toward a central drain, thus permitting the occasional use of a hose. In the event that roaches are brought in, e.g., in hay, the immediate and radical use of a mixture of equal parts of sodium fluoride and borax is indicated.

Temperature Control. The room itself should be as light and as airy as possible, although care must be taken to avoid drafts. Where small animals are used in metabolism experiments, it is highly important that careful control of the tempera-

ture should be maintained, e.g., in working with albino rats the room temperature should range between 72 and 76 degrees F., particular care being taken against a drop in temperature. If the building is heated by steam or hot water, a regulating device should be attached to a thermostat placed at a representative point in the room. In those places where the heating system is turned off at night or over the week-end, special provisions must be made for maintaining the temperature at the above mentioned level. The choice of devices for this purpose is not very great. There may be mentioned, however, the rather elaborate gas hot water boiler connected to separate radiators, which may be installed by the local gas company, and individual gas-heated steam radiators controlled by individual thermostats.

Screens. All windows of the animal room should be completely screened and this, together with the frequent use of a spray, should provide adequate protection against flies.

Diet Room. Adjoining the animal room there should be a room for the storage of feeds, special diets, bedding, etc. This room might also be used for the preparation of experimental diets and should contain, in addition to storage bins and closets, a platform scale for weighing large quantities of materials, a trip scale for smaller quantities of materials, a chemical balance for more accurate weighing of dietary supplements for small animals, a diet-mixing device, a number of metal cans for storage purposes and a spacious refrigerator, preferably of the gas or electric type. If the nature of the work demands, an ultraviolet lamp might also be included for the irradiation of experimental diets. This room should also be provided with a sink constructed so that sufficient space is allowed between the faucet and the bottom of the sink for the introduction of tall containers.

Sterilizing Room. Adjoining the animal quarters there should also be a room devoted to the cleaning, disinfecting and sterilizing of cages, food dishes, etc. A large deep sink, either galvanized or enameled, will usually suffice for cleaning small cages by the hot soap suds-CN method. If space is available, however, it is highly recommended that a large, galvanized iron, steam sterilizer be installed, with the steam outlet extending outside the building. If such a sterilizer is properly constructed with rubber gaskets, there should be very little escape of steam into the room.

Animal Cages. Where much work is done in the field of nutrition and metabolism, it is very desirable to separate different species of animals as far as possible, in order to avoid the transmission of bacterial or parasitic infections and also to avoid the possibility of contamination of experimental diets. In general, animal cages should be constructed as far as possible entirely of metal, so that complete sterilization is possible. Cages may be constructed singly or in multiple units arranged in tiers. It is advisable, however, not to have the individual units too large so that they may be knocked down for cleaning purposes.

Dog Kennels. Dogs for experimental work may be kept in kennels described above. If it is not possible to construct these kennels in a penthouse, it may be desirable to build a runway to the roof of the building, so that the animals can get out into the air occasionally.

Compartments may be constructed above the dog kennels for keeping stock rabbits and guinea pigs, but ordinarily when they are placed on experiments, these animals should be transferred to metal cages.

For metabolism work on dogs a special type of cage must be used provided with a wire screen bottom to retain feces, below which is a funnel-shaped tray, draining into a large bottle which contains a preservative for the urine, such as toluol. These so-called metabolism cages may be constructed individually or in tiers. Individual cages may be built on casters.

Cages for Rats. Small cages for rats or mice may be placed on portable steel shelves so that they may be moved around with facility. Individual rat cages should be set in pans with sloping sides, so that the pans may be stacked after cleaning. These cages should have wire screen bottoms to allow excreta to fall through and collect on absorbent paper in the bottom of the trays or pans. Larger oblong cages may be used for stock animals or for breeders.

In certain types of work with rats, special precautions must be taken to prevent exposure of the animals to direct sunlight. For nutrition work on small animals a rolling table should be provided to enable the worker to move the food and animal scales around the laboratory when weight records are made.

X-Rays. Where any volume of research work is done on the

metabolism of bone, it is desirable that special roentgenographic apparatus to be set up in or near the animal room.

Operating Room. A very valuable asset to an animal laboratory is an operating room. This should be constructed of white tile with all the refinements of a hospital operating room. Along the walls there should be a laboratory table, provided with gas, electricity, sinks, etc. The room should be very well lighted, both naturally and artificially. A central floor drain should be provided to facilitate mopping up after operations. A separate sink, operated by the foot and knees, is an almost indispensable part of the operating room equipment. An operating table should be set up in the center of the room and provided with removable animal boards of different sizes. The room should also contain an instrument cabinet with a complete surgical and dissecting outfit. One corner of the operating room might be devoted to a large, deep sink or small tub to serve as a bath for the dogs.

Incinerator. Finally, too great emphasis cannot be laid upon the importance of having an incinerator in the basement of the building devoted to biochemical work. Immediate disposal of dead animals and operating room waste must be made out of deference to the olfactory sense.

CHAPTER XXI

SANITARY AND BIOLOGICAL RESEARCH LABORATORIES

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Introduction. A laboratory should be designed to meet the requirements of all phases of the work which the staff may be called upon to perform, and this is especially true of the research laboratory as contrasted with one planned for class work. The work of the Division of Laboratories and Research of the New York State Department of Health is unusually broad in scope, and this applies to its routine activities as well as to the research. The design of the laboratories, therefore, had to meet the needs of pathological, bacteriological, and serological work, and, in addition, the varied activities of analytical, sanitary, biological and physical chemistry—all interrelated and coordinated. Certain of the routine procedures, such as the examination of specimens for evidence of infectious disease and the preparation of biologic products—sera, antitoxins, and vaccines—which involve well-defined, prescribed technical procedures, demand such special design and arrangement of the technical apparatus that these requirements could only be met by separate laboratories: thus the original laboratory building, 150 by 50 feet, three stories and basement, which was planned for research, has been enlarged by the construction of two wings, 50 by 100 feet each, two stories and basement, one for the diagnostic, and the other for the serum laboratories. The main building has so satisfactorily fulfilled its purpose that it constitutes a basic nucleus capable of adaptation to nearly any phase of pathological, bacteriological, serological, or chemical research. The author has, therefore, limited his

description of a research laboratory in which sanitary or biological chemistry is done, to the plan and equipment of his own laboratory,[1] supplementing this description by an appendix, in which some of the main items of equipment are listed, followed by a reproduction of the construction plans. Only a few of the adaptations which this design permits are mentioned, for purposes of illustration, because so many requisites of these closely related lines of chemical work have been dealt with in other chapters devoted to analytical, organic, and physical chemistry.

Scope of Laboratory. The research laboratory not only requires a convenient arrangement of the technical equipment, but also general service from accessory departments, the development of which depends largely upon the volume of work. There should be a library, secretarial, and administrative service; adequately equipped stock room and purchasing department; and, depending upon the extent to which bacteriology and pathology are involved by the investigations into sanitary and biological chemistry, service departments for the sterilization of glassware and preparation of media, and animal quarters.

Library and Museum. The importance of library facilities is universally recognized, but, in addition, every laboratory should have a museum illustrating the scope of its work. The value of such a museum, not only for reference but for training, and broadening the background of the younger workers, cannot be overestimated, yet it is rarely appreciated. Although in progress for ten years, the development of the museum here has been impeded owing to lack of space and personnel and has never reached a useful or practical stage.

Animals. Biological chemistry often includes experiments on animals, and the number and kinds needed vary according to the demands of the work. In this laboratory, horses, mules, cattle, sheep, goats, pigs, guinea-pigs, rabbits, mice, rats, dogs, cats, monkeys, snakes, fish, and birds—particularly chickens and pigeons—have been used from time to time. Provision should be made for housing such animals, but to deal adequately with this problem one would need an additional chapter. The reader may refer to the appendix for a few of the

[1] As Dr. Wadsworth has described an existing laboratory, the Committee publishes his paper as received, though at times his views and practice may be at variance with its opinion as expressed in other parts of this book.

satisfactory types of animal cages for general laboratory use, and to catalogues describing special cages; also, details covering care and housing of animals are to be found in the published Standard Methods of the laboratory.

Although essential to much of the work, these features are such specialized phases of it that they do not fall within the scope of this chapter which is devoted to the plan of the research building, especially the design and arrangement of the technical facilities.

General Type of Building

Location. Certain architectural features of the building are extremely important. The central corridor with rooms on either side makes for economy of space and time, and facilitates the use of the apparatus. The building faces the north so that the long axis is east and west and the arrangement of the laboratory rooms such that, so far as practicable, they have the north light, which is essential for work with the microscope. The library and preparation rooms are not so seriously inconvenienced by a southern exposure. If practicable, the laboratory should not be near the congested manufacturing districts of a city; preferably, it should be situated where there is plenty of space and air, free from soft-coal smoke, and fumes.

Vibration. The buildings should be of fireproof construction. Reinforced concrete is probably least affected by vibration. If possible, elevators, and equipment which is likely to cause vibration, should be installed independently of the main construction. The vibration of a building, however, varies greatly, depending on its location. It may be impracticable to avoid this disadvantage, and, therefore, necessary to provide separate foundations or piers in the basement for physical and other equipment. Such additional supports were not required in this laboratory which stands 125 feet from the sidewalk and is remarkably free from vibration even in the rooms on the third or top floor.

Lighting. The windows should provide ample light and, preferably, extend to the ceiling so as to throw the light into the room: 18 to 20 feet is the approximate distance that light is carried satisfactorily into the room (height of ceiling 12 feet) and

is, also, a very convenient dimension for a laboratory. There are certain objections to mullioned windows, especially in microscopical work, because they are projected into the field of the microscope. Nevertheless, it is impracticable and costly to have the panes of glass too large. The size of the panes in the partitions of the draft-free enclosures built within certain of the rooms permits microscopic study at the bench.

Walls. The walls of the laboratory should be plastered and painted. Glazed brick provides a very desirable surface, but is more expensive and scarcely necessary in a building for sanitary and biological-chemical research. Plaster provides a smooth surface which can be painted and repaired and thus kept clean as easily as any of the more expensive materials.

Floors. The floors should be of concrete covered with battleship linoleum, or of wood. The wooden floor is more comfortable for the worker who stands, but is less desirable, possibly dangerous, in case of accident with inflammable substances. On the whole, battleship linoleum on concrete is most economical and suitable for this purpose.

Heating. The most satisfactory type of heating system is that obtained by low pressure steam with gravity, or possibly, a vacuum-return system and thermostatic control may be preferable. The Johnson thermostat gives as good service as any with which we have had experience, but the control depends to a large extent upon the location of the regulators. The principles governing heat regulation under ordinary conditions in office buildings do not obtain for laboratory rooms, and the advice of experts is usually faulty on this point. In a laboratory, the greater part of the work is done at tables nearest the light, or along the outside walls, and the radiators should be distributed in each window recess so that the heat arising from them will counteract the downward draft of the cold air. Experts do not advise a location of thermostats on the outside walls, but it is necessary to have them near the source of heat in order to secure the most satisfactory control. Often, however, they must be placed on the exterior walls and, in that case, should be set on insulated mats so that they will not be affected by the cold. Corners of the room where the air does not circulate freely should also be avoided. If the thermostats are placed on the

interior wall, distant from the radiators, the worker at the tables is apt to be uncomfortable because there is often a variation of 10° in different parts of the laboratory room. Then, too, considerable heat is generated by Bunsen burners, steam baths, and the like, which often overheat the rooms so that the thermostats do not operate the radiators which remain cold throughout the day. Thus, if the problem is not carefully studied, the outer zone, in which much of the work is done, is cold, while the interior is overheated.

There is another disturbing feature in the heating of a laboratory, namely, that the firemen start the boilers so early in the morning that the rooms are fully heated and the radiators shut off by the thermostats before work is begun. By proper timing or by thorough ventilation at intervals this difficulty can be easily overcome.

Ventilation. There are various ventilating systems in vogue. Owing to lack of experience with any of them, they were avoided in the construction of our laboratories. If they are used, the arrangement of intakes and outlets must be very carefully considered to avoid short-circuiting of the currents of air or disturbance when the windows are open in warm weather. Although no separate ventilating system was installed in the building, the vent ducts for the fume hoods, draft-free rooms, and the like, were sufficiently numerous and carefully located to provide not only for their ventilation, but for that of the main room as well. All these ducts are located in the interior wall of the room at points farthest away from the windows, which have no weather strips, and leak a sufficient amount of air to keep the room fresh; if necessary each window may be raised slightly.

The flue vents are vitrified tile set in concrete rising vertically in the center of the building. Horizontal runs of this construction, however, should be carefully avoided; in this laboratory they are of replaceable metal covered with acid-proof paint. Individual fans may be connected with a service switch at the fume hood or a common fan connected to several ducts may be installed. A minimum of two fans, each arranged to operate all of the ducts, so that they may be interchangeable, should be provided. There are some advantages in such a system, because it provides for ventilation, and corrosive gaseous materials are diluted before they reach the fans. It may be necessary, how-

ever, to separate some of the ducts and provide a non-corrosive material.

Hoods. Fume hoods are installed in all the laboratories. Depending upon the character of the work, the chemical hoods may be constructed of white enameled metal, alberene, or wood All the hoods in this laboratory are of white enameled metal and glass, which affords the lightest and best construction if adequate protection against fumes is provided. The alberene hoods are darker and less attractive, but not affected to the same extent by fumes. The same may be said of wood which is, perhaps, in addition, dangerous in case of accident. In any event, the back of the hood should be lined with white tile to reflect the light. Some chemists prefer also to have the bench of the hood tiled, preferably with Austrian tile, which is peculiarly well adapted to this purpose and is used in the research laboratories of Professor Theodore W. Richards at Harvard University.

Separate ducts made of vitrified tile, having one outlet at the top and another at the bottom of the hood, extend from each hood to the ventilating system. The hoods in the bacteriological laboratory rooms are equipped with gas, vacuum, air pressure, hot and cold water, a small 5-inch porcelain sink, and also outlets for plugging in electrical equipment. In the Director's private laboratory, in the various chemical laboratories, and in the media room, the fume hoods are further equipped with steam baths.

Steam Baths. Various steam baths have been designed for the hoods, but none of them meets all requirements. Those in our laboratory are constructed of alberene, lined with copper, and set in the bench flush with the surface. Alberene caps fit into circular openings so that there is an even surface when the bath is not in use. Owing to differences in expansion, some of the joints have separated; particular attention should, therefore, be given to this detail in constructing such a bath. Sand baths have been suggested as an improvement and for temperatures above 100° C.

Draft-free Rooms. It will be noted on the plans that there are small, separate draft-free rooms with glass partitions, approximately 7 feet by 5 feet. These were originally designed to protect against drafts and the contamination of cultures, or for dangerous work, but have also proved very useful for special

phases of biochemical work. These rooms contain the complete equipment found in the hoods with the exception of the steam baths. They are ventilated above by a space between the partition and ceiling which is covered by a wide apron outside and a narrow one inside the room, with a view to excluding dust and yet facilitating the entrance of air. The rooms are also connected with the exhaust fans by ventilating ducts similar to those in the hoods. Ochre paint, which presumably excludes the violet ray, has been used on the glass partitions where it is necessary to protect the operations from direct or indirect sunlight.

Supply Lines. All supply lines are accessible and are arranged in vertical chases extending from the basement to the top of the building with a large panel door, provided with lock and key, extending from the floor to the ceiling. To avoid carrying pipes in the ceilings, a false ceiling in the central hall of the building provides for horizontal distribution to the different rooms of the floor above; then, in the rooms, the distribution above or below the tables leaves all pipes accessible. The false ceiling in the hall provides a space of from nearly 2 to 3 feet with openings at intervals, so that the piping is accessible and yet not unsightly or so liable to drip. We found, unfortunately, a few exceptional situations in which distribution could not be solved this way, and it was necessary to run the pipes exposed in the ceiling.

Drains. The vertical drains should be made of vitrified tile set in concrete, or duriron, and the horizontal drains of cast iron or duriron. If cast iron is used it may be necessary to replace some of the drains with lead. Lead-lined pipe should be avoided; cast iron or duriron is most suitable for permanent installation.

Plumbing. Brass pipe is essential for the hot water, but not so necessary for the cold water supply. It is well to ascertain the character of the water, however, before making a decision. Hose bibs are often convenient on the faucets and also a combination faucet delivering hot and cold water. The spun brass, gooseneck faucets on the market are not desirable. These should preferably be constructed of brass pipe filled with sand and bent to complete a semicircle of the diameter required in order to deliver a vertical stream of water. All faucets should center, so far as possible, over the drain.

Sinks. There are various types of cocks for the vacuum,

pressure and gas outlets which are satisfactory. Similarly, various types of sink have proved suitable for laboratory work and the selection is largely a matter of individual preference. In the tables and hoods of this laboratory there are small porcelain desk sinks, 5 inches square, set so that the alberene overhangs the edge and protects against splashing to some extent. Larger porcelain and earthenware sinks have recently come into vogue, but the alberene sink is neat and in every way desirable, if not too large. There has been some difficulty with the largest sink in the laboratory, 60 inches in length, owing to differences in expansion. It is convenient and practical to have the alberene drain boards set level, with grooves draining into the sink. Occasionally, the alberene suffers from heavy usage and may be covered with lead. The standard design of the alberene sink (see appendix) may be constructed in wood and covered with lead. This is, perhaps, an economical type.

Refrigeration. Facilities for dialysis, filtration and other operations at low temperatures are now essential in all biological-chemical laboratories. A cold room, provided with vacuum, pressure and electrical outlets, should be available where temperatures below 0° C. may be maintained. Refrigeration may be obtained now by small individual units such as the Kelvinator, Frigidaire, or General Electric. The central ammonia-refrigeration plant, with brine tank and brine circulating in the different cold rooms, has proved most satisfactory in our experience. In the brine tank, provision is made for the manufacture of ice and for the storage of materials at temperatures well below freezing. Small refrigeration units, if sulphur dioxide gas is used in the compressor, are not adapted to this purpose, as low temperatures cannot be maintained.

Special Features. The importance of a shower installed in the chemical laboratories, or immediately accessible to them, and a first-aid room in case of accident, should not be overlooked. There should also be a separate combustion room and a room with electrical heating facilities for operations involving the use of ether and other inflammable, volatile substances.

Standard Units

It is a great convenience to have standard units and dimensions, so far as practicable, throughout a laboratory. The dimen-

sions of the tables, vacant spaces, and furniture should be related. This greatly facilitates the changes necessary to meet the requirements of special work.

Size of Unit. The unit dimension which has been selected, and found convenient after ten years' experience, is 30 inches. The tables are 30 inches wide and 30 inches high in the bacteriological rooms, or 36 inches high in the chemical laboratories, but where chemical and bacteriological work are combined, as in some branches of biological chemistry, the lower bench is not inconvenient. Thirty inches, when one considers the space taken

Fig. 114. Analytical Laboratory showing the Extension of Table Facilities by Units to provide, in this instance, for Combustion Furnace.

by the sink and outlets, is too narrow for the hoods, and 36 inches is the limit for convenience; the benches in the hoods have thus been built 36 inches wide and 36 inches from the floor. The sinks approximate 30 by 30, outside dimensions, and the drain boards, 30 by 30; the furniture—desks, tables, and the like—are in multiples of this dimension, 15 by 30, 30 by 30, 30 by 60, and 60 by 60. The tops of high tables, cupboards, and so on, are 36

inches from the floor; the others are 30 inches from the floor. With these units, adaptable to any rearrangement of the laboratory room, it is possible to meet the demands of any special problem.

Arrangement of the Laboratory Work Room

Unit Plan. There are two main principles underlying the arrangement of the technical equipment in the laboratory work room. The permanent equipment may be arranged around the circumference of the room, leaving the center free for future extensions, or vice versa, it may be placed in the center of the room. The peripheral arrangement has proved a most convenient and adaptable plan; the central, much less so. Adopting the unit dimension of 30 inches, the convenient depth of the room can readily be figured: 30 inches for the table on the outside wall; 4- or 5-foot passageway, and 60 inches for a central double table or desk, with 4- or 5-foot passageways the other side; 3 feet for the installation of hoods and supply lines back of them, totals a depth of 18 or 20 feet which is about the maximum for the distribution of light from the windows.

Rooms. The length of the room should be determined by the amount of work that is to be done in it. As shown in the plans, provision has been made for groups of adjoining rooms for special work: between the larger rooms, approximately 25 feet long, are two smaller ones, about 15 feet long, all connecting the length of the building. The research workrooms should provide space for one research chemist and one, or possibly two, assistants. It is a mistake to construct smaller units. The arrangement of the rooms can best be seen by consulting the plan. The smaller rooms shown there are satisfactory for bacteriological and serological research, but may not be adequate for research in chemistry unless the amount of equipment involved is very limited.

Table Commodities. The alberene tables extend around the periphery of the room. The sinks are located so that the supply lines and drains suffice for the sinks of two rooms and the drains collect from the smaller sinks in the wall benches. Thus, the hot and cold water, gas, and electricity supplies extend around the periphery of the rooms exposed above the tables. The vacuum and pressure in the larger rooms are carried to the middle of the

end of the rooms so that, if necessary, they can be extended from this point, together with the other supply lines, to tables in the center of the room. This, however, has rarely been necessary in our experience.

Clocks. The convenience of a system of clocks operating from a central clock should not be overlooked. In every workroom of the laboratory a large-face electrical clock has been placed so that it is easily seen from all parts of the room. Such a system, although it does not serve every purpose, becomes indispensable in the modern laboratory once its practical value has been demonstrated.

Telephones. Similarly, a private branch exchange with telephone extensions in all the laboratory workrooms greatly facilitates the very necessary contacts without loss of time.

Special Laboratories

Arrangement. The rooms for analytical, sanitary and biological chemistry are all similarly arranged with the exception of installations for special work. In the larger rooms, there are two 8-foot hoods, containing steam water baths, the openings of which differ depending upon the character of the work: in the analytical laboratories the openings are 2½ and 5¼ inches in diameter, whereas in the biological rooms besides one large opening, 11 inches in diameter, there are several smaller ones, 5¼ and 2½ inches. Adjoining the analytical laboratories there is a combustion room. In a small, separate hood, the apparatus for Kjeldahl digestions is connected with the vitrified tile vent: a horizontal, rectangular, vitrified tile is set in the wall of the back of the hood. The openings at intervals in the tile take the necks of the flasks. Thus, all the fumes are carried up by the suction of the fans in the attic where all the flue vents are joined to a common duct and outlets. Distilled water is delivered in block-tin pipes from tanks in the attic to the sinks of these laboratory rooms. The block-tin pipe connects directly with a special silver-plated faucet such as is used in soda-water fountains. This has proved very satisfactory.

Biochemical Equipment. In one of the rooms for biological chemistry there is a large water bath, 30 by 60 inches, with covers, and so connected that it may be heated by a steam coil or gas. This bath is used largely for the precipitation of the

globulins from blood serum with ammonium sulphate and may be maintained without difficulty at a reasonably constant temperature. The hydrogen-electrode apparatus and the potentio-

Fig. 115. Chemical Laboratory (Southwest Aspect).

meter for the electrometric determination of hydrogen-ion concentration are also installed in this room. Connecting with the biological-chemical laboratory are two cold rooms: one provides for the storage of materials; the other contains a dialyzing sink with a tank chilled by circulating brine under thermoregulation

so that the water is delivered to the dialyzing sink slightly above the freezing temperature. This equipment permits of prolonged dialysis and at the low temperature prevents the growth of bacteria, molds, and the like.

Electric Lines. In all the laboratory rooms, the electric supply lines are wired to carry 30 amperes and fused to 25 amperes, each room being equipped with additional fuse boxes to which may be attached the medium-sized centrifuges, shaking machines, and the like, which do not cause disturbing vibration of the building. The larger maxciforce centrifuge is installed in the basement.

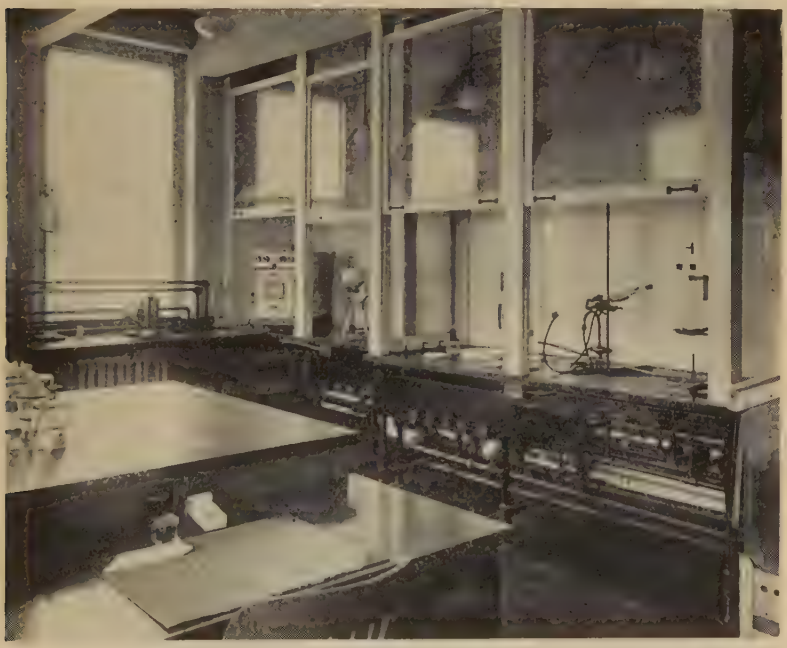

Fig. 116. Chemical Laboratory Showing Hoods (Northwest Aspect).

Other Equipment. In addition there is a separate room equipped with stills for alcohol and for water so that it is possible to recover a part of the alcohol used in the laboratory. A large drying oven has been much needed. The balance room also provides space for the spectroscope, but with increased work it has been found necessary to make a separate installation. The design of the present laboratory has been found satisfactory for

housing the delicate new equipment used by Pregl in his microchemical analyses. This special equipment—drying oven, still, balances, spectroscope, and the like—has doubtless been more fully described in chapters devoted to other branches of chemistry; this is true also of the furnaces for combustions since this equipment is common to practically all chemical work.

Fig. 117. Kjeldahl Laboratory Showing Hoods (Northwest Aspect).

Filtration. The operations of filtration have not been developed here to the extent one finds in other laboratories, par-

ticularly the large commercial houses, but in this laboratory the work is so specialized that the appliances are not suitable for general use. The various types of filtration which experience

Fig. 118. Dialyzing Room with Brine Cooler, Temperature Control Tank above to Supply Dialyzing Sink.

has demonstrated to be of practical value may be listed as follows: filtration through porous candles of the Chamberland-Pasteur, Berkfeld or Mandler type. The Seitz filter is a useful aid; also

the Bechold apparatus for ultrafiltration. Electro-dialysis by Ruppel's membranes is one of the newer methods, the practical advantages and limitations of which have not as yet been clearly defined.

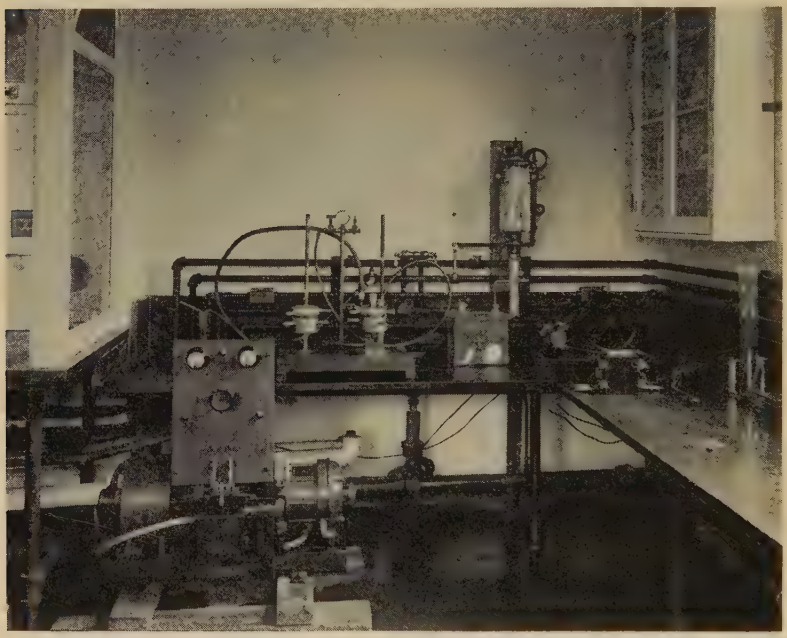

Fig. 119. Bechold's Apparatus for Ultrafiltration and Ruppel's Equipment for Electro-Dialysis (Direct Current Generator in Foreground).

In conclusion, the reader is referred to the appendix for a list of some of the equipment which, in our experience, has been found satisfactory. Such a list must obviously be reviewed critically by any one making selections because much of the equipment is for special purposes and the apparatus in general use may have been superseded by recent developments. For further details of construction and equipment the reader is referred to the plans which should be legible with the aid of a magnifying glass. It should be noted that the grouping of outlets, arrangement of sinks, hoods, and the like is quite similar throughout the building with the few exceptions mentioned above or shown in the illustrations.

APPENDIX

SECTION I

Laboratory Apparatus and Equipment

All alberene equipment is treated with dressing wax prepared and applied as follows:

Paraffin	450 grams
Gasoline	340 cc.
Kerosene	340 cc.

Melt paraffin in water-bath, cool to about 60° C. and add the kerosene slowly, stirring constantly. Then add the gasoline and mix well. Keep tightly corked and do not bring near a gas flame.

The dressing should be warmed in a water bath until it becomes fluid, and a thin coating applied with a cloth to the alberene. It should be allowed to stand several minutes and the surface then polished with a soft dry cloth. When the paraffin coating becomes dull from use, the dressing may be re-applied. The best results are obtained when the alberene is not too cold.

The hard maple tops of table-desks, tables, and cupboards are carbonized and made acid-proof by finishing solutions prepared and applied as follows:

Solution No. 1

Copper sulfate	125 grams
Potassium chlorate	125 grams
Water	1000 cc.

Solution No. 2

Aniline hydrochloride	150 grams
Water, warm	1000 cc.

Solution No. 3

Potassium bichromate (10%)	100 cc.
Hydrochloric acid (5%)	50 cc.
Water	1000 cc.

Apply one coat solution No. 1; allow to dry.
Apply second coat solution No. 1; allow to dry.
Apply one coat solution No. 2; allow to dry.
Apply second coat solution No. 2; allow to dry.
Apply one coat solution No. 3; allow to dry.
Wash with warm soap suds and rub down with linseed oil.

Wall Tables

Wall tables made of 1½ in. alberene, 30 in. wide and 30 or 36 in. from the floor, supported on a pipe-leg frame work or, preferably, with horizontal angle irons parallel to the wall at the rear and front of the tables on metal brackets fastened to the outside wall by anchor bolts imbedded in the brick work.

Standard Laboratory Work Sink

Made of alberene slabs, 12 by 20 by 30 in. inside dimensions with 3½ in. rim, supported on frame of iron pipe fastened to floor by bolts; one side of sink and end of drain board supported by angle iron secured to wall by bolts. Rim, and horizontal drain board, 30 by 30 in., grooved to drain into sink, are 36 in. from floor. Sink provided with three faucets, central one supplying mixed hot and cold water, with outlet centered over drain. Drain outlet equipped with removable standing overflow pipe 10 in. long.

Sinks in Hood, Wall Tables and Draft-free Room Tables

Made of vitreous ware, approximately 5 by 5 by 5 in. inside dimensions; flat rims with integral overflows, secured to underside of alberene wall tables by bolts and clamps and provided with ¾ in. brass combination faucets (except in fume hoods and draft-free rooms where they are gooseneck type) with outlet threaded for hose connection. Faucets center over drain which is stoppered with 1½ in. acid-proof waste plug.

Vats

Three copper-lined alberene vats, approximately 27½ by 27½ by 21¼ in. inside dimensions, installed in the preparation room (see plans) and braced by means of acid-proof angle clips bolted through the stone. Each vat provided with sheet iron cover of No. 12 gauge plates, with hasp hinges, catches and handles, cover heavily galvanized *after construction*. Waste outlets and standing overflows of standard acid-proof metal. Two outer vats supplied at ends with hot and cold water. Spouts extend into vats and are controlled by angle valves located under adjacent table tops with handles extending through them. Central vat provided with heavy brass combination faucets located outside with spouts extended into vat.

Dopp Steam Kettle

Specially constructed kettle for cooking meat extracts, gelatines, and so on; 15 gal., high jacket, seamless, cast iron, jacket tested and tight at 150 pounds hydrostatic pressure, fitted with cast through outlet, strainer, and 1¼ in. brass faucet threaded for standard pipe and screwed into threaded bronze bushing inserted into the outlet.

Autoclaves

Steam autoclaves, 15 pounds normal operating pressure, special construction and design, to carry 30 pounds pressure, with connections to vacuum and air pressure systems as well as steam in the inner chamber and jacket; provided with registering and indicating thermometer connections.

Sterilizers

Autoclave type, special design and construction for steam at 130 pounds pressure in jacket only, also with registering and indicating thermometer connections. May be used for either dry air sterilization at 150° to 160° C. or for steam sterilization at 15 pounds pressure producing 120° C.

NOTE—A very convenient and reliable method of dry air sterilization at 150° to 160° C. has been accomplished in the laboratory by use of steam under high pressure, approximately 130 pounds. It is possible, however, that the units installed in this laboratory are too large for efficiency; the chamber is approximately 36 by 54 by 48 in. and time is lost in heating such a large volume of air.

Experimental Extraction and Distilling Apparatus

Consists of 20 gal. heavy copper steam-jacketed still equipped with rectifying column and extraction chamber with steam and water connections.

Water Still

Consists of still and condenser mounted above block-tin lined storage tank,

all connected to water, steam, waste and block-tin distilled water supply pipe lines.

Alcohol Still

Consists of 10 gal. inner container provided with removable top and immersed in a water bath heated with a steam coil within the jacket; fitted with interchangeable reflux and direct condenser.

Distilling Apparatus (for determination of ammonia in water).

Consists of 6 block-tin straight condenser tubes in copper condensing tank fitted with adjustable gas burners.

Kjeldahl Distilling Apparatus

Consists of 4 block-tin straight condenser tubes in heavy copper condensing tank fitted with adjustable gas burners.

Refrigerators

Cold boxes of special design and construction with removable trays and drawers of Monel metal.

Electric Centrifuges

Type SB, sizes 1 and 2; 5-liter maxciforce.

Laboratory Super-Centrifuge (for application of very high centrifugal force to liquids).

Water Baths

Copper water bath approximately 60 by 30 by 20 in., with or without covers, specially designed for gas, electricity or steam heat.

Table-Desks

Size 60 by 60 by 36 in. consists of two units each of which is made up of two side tiers of drawers (4 each) separated by a center drawer with recessed cupboard below. Between the two units is a long drawer for glassware so constructed as to pull either way. Tapered legs, 2 in. square.

Size 60 by 30 by 36 in. consists of one unit as described above but without long drawer for glassware.

Cupboards

Sizes 30 by 30 by 36 in. and 30 by 15 by 36 in.

Desks

Size 60 by 30 by 30 in., quartered oak, double pedestal, flat top; left pedestal, 3 single drawers; right pedestal, one single and one double drawer; one single center drawer. Drawers equipped with interchangeable partitions adjusted for 3 by 5 in. and 4 by 6 in. card systems.

Animal Cages

Type I. Metal cages of galvanized iron wire (17 gauge No. 3 mesh) 78 in. total height, each a solid stack of five compartments (48 by 24 by 14 in.) built on a 1 in. angle iron frame with legs 8 in. high. Each compartment has a central sliding wire door and, for ease in cleaning, two removable trays (24 by 24 by 2 in. high) which rest on slides made from angle iron. A folded metal strip is slipped over the edges of the adjoining sides of the trays. Each compartment is designated by a number stenciled on the front of the cage.

Type II. Metal cages of galvanized iron (19 gauge) of same size and type as No. 1 but with two sliding wire doors, and a removable central partition which may be used to divide each compartment into two divisions. Each division is designated by a number.

Type III. Metal cages of galvanized iron (19 gauge) 78 in. total height, consisting of a solid stack of five compartments (30 by 15 by 14 in.) having wire mesh fronts with one sliding door in each, and removable trays. A number is stenciled on each compartment.

Type IV. Metal boxes of galvanized iron (22 gauge) made from one piece with rolled edge top reinforced by heavy wire (6 gauge); wire mesh (No. 3) sliding covers with drop ring handle. Three sizes used 6¾ by 7½ by 5½ in. high; 13½ by 15 by 5½ in. high; and 16 by 15 by 11 in. high. Racks for metal boxes 30 by 15 by 78 in. high; frame of ¾ in. angle iron with 8 adjustable shelves of galvanized round iron bars.

SECTION II

Plans of the Laboratory Building

Fig. 120. Basement Plan.

The engineering plans were selected for purposes of illustration in the hope that with the aid of a magnifying glass it would be possible to see not only the arrangement of the rooms but

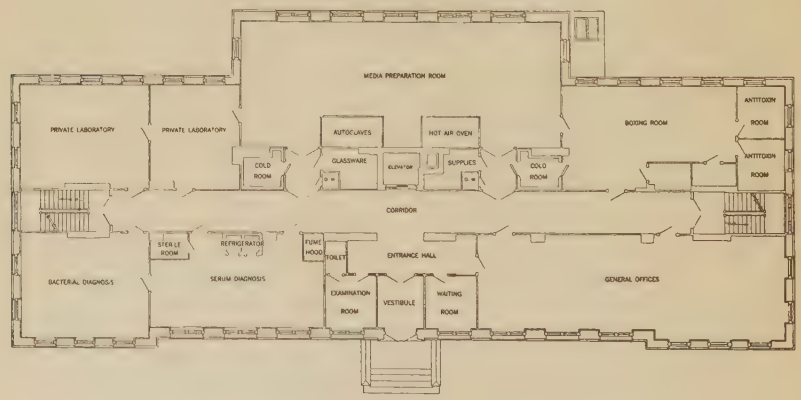

Fig. 121. First Floor Plan.

also much of the permanent equipment, but the plans had to be redrawn to fit the exigencies of printing. However, the general idea has been kept. The draft-free rooms were originally designated as sterile rooms, but this early proved a misnomer, hence the substitution. Some of the rooms designed for bacteriologi

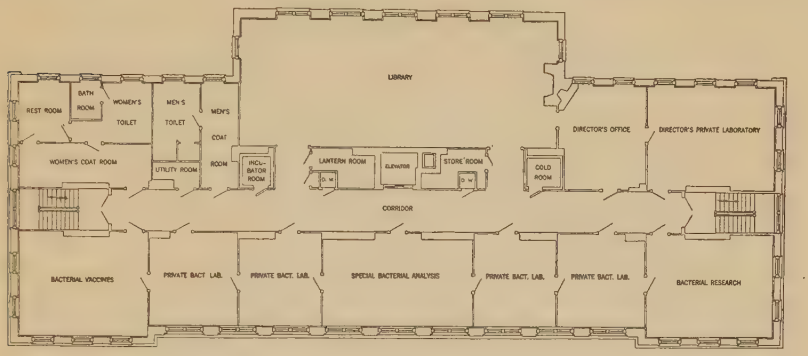

Fig. 122. Second Floor Plan.

cal research are now used for chemical research and the fact that the tables are only 30 inches from the floor instead of 36 inches, as in the original chemical laboratories, has proved of no serious inconvenience in the work, especially since the central table desk units are all 36 inches from the floor.

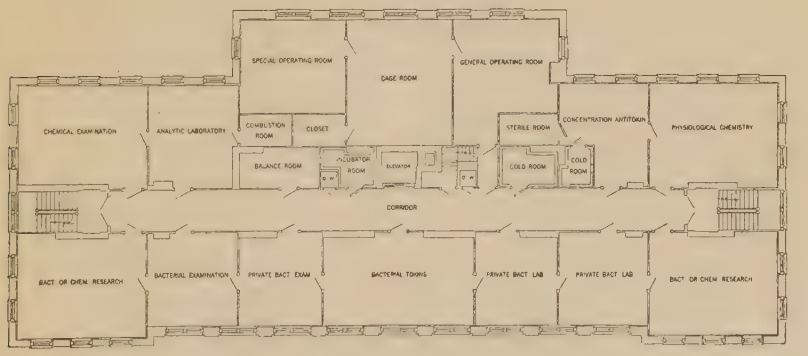

Fig. 123. Third Floor Plan.

I wish here to express my appreciation of the courtesies extended by the present state architect, Mr. William E. Haugaard, in giving permission for the reproduction of these plans. I wish also to acknowledge my indebtedness to Mr. Lewis F. Pilcher,

state architect at the time the main building was under construction, and to his staff, Mr. Thomas Newton, Mr. C. A. Suss-

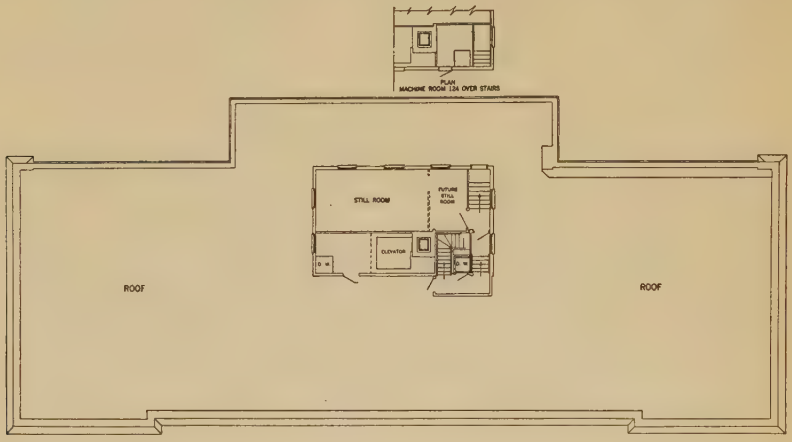

Fig. 124. Roof and Pent House Plan.

dorf, Mr. G. B. Nichols, and Mr. R. C. Taggart, for their close cooperation and for the careful study they made of the problems involved in the plan and design of the laboratory.

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